PB81-184574

Historical Emission and Ozone Trends in the Houston Area

Technology Service Corp.
Santa Monica, CA

Prepared for

Environmental Sciences Research Lab.
Research Triangle Park, NC

Apr 81

U.S. Department of Commerce
National Technical Information Service
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TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/3-81-027	2. ORD Report	3. RECIPIENT'S ACCESSION NO. PB81 184574
4. TITLE AND SUBTITLE HISTORICAL EMISSION AND OZONE TRENDS IN THE HOUSTON AREA		5. REPORT DATE April 1981
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) M. Davis and J. Trijonis		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Technology Service Corporation 2950 31st Street Santa Monica, CA 90405		10. PROGRAM ELEMENT NO. C05A1A/01-0642 (FY-80)
		11. CONTRACT/GRANT NO. 68-02-2976
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Sciences Research Laboratory--RTP, NC Office of Research and Development U.S. Environmental Protection Agency Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE EPA/600/09

15. SUPPLEMENTARY NOTES

16. ABSTRACT

An analysis of historical trend data for emissions and air quality in Houston for period of 1974-78 is conducted for the purposes of checking the EKMA O_3-predicting model and of exploring empirical relations between emission changes and O_3 air quality in the Houston area. Results from the EKMA testing analysis were inconclusive mainly because the O_3 air quality changes during the 1974-78 period were very small. Results from the emissions-to-air quality empirical relationship analysis explained the previously noted paradox that the O_3 air quality did not improve despite substantial control of hydrocarbon emissions during 1974-78. The explanation is that source growth during that period nearly offset the effect of emission controls and that many such controls were installed prior to 1974.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 138
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

PB91-184574

EPA 600/3-81-027
April 1981

HISTORICAL EMISSION AND OZONE TRENDS IN THE HOUSTON AREA

by

Marilyn Davis
John Trijonis
Technology Service Corporation
2950 31st Street
Santa Monica, CA 90405

Contract 68-02-2976

Basil Dimitriades
Atmospheric Chemistry and Physics Division
Environmental Sciences Research Laboratory
Research Triangle Park, NC 27711

PRODUCT OF:
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

ENVIRONMENTAL SCIENCES RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

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ABSTRACT

An analysis of historical trend data for hydrocarbons, nitrogen oxides, and ozone in the Houston region from 1974 to 1978 is conducted in order to check the EKMA ozone model and to obtain a better understanding of the Houston ozone problem. In addition to historical trend analyses, the study includes a detailed investigation of seasonal/diurnal/meteorological patterns in ambient ozone data at two Houston monitoring sites (Mae Drive and Aldine).

Historical emission trends are compiled for 26 NMHC source categories, for 15 NO_x source categories, for each year from 1974 to 1978, and for five sub-areas of the Houston region. It is found that estimated NMHC emissions in the Houston region decreased 17% from 1974 to 1976 but then increased 12% from 1976 to 1978, so that there was only a slight net decrease over the 4-year period. Estimated NO_x emissions increased by 18% over the 4 years. These emission trend estimates involve significant uncertainties. Ambient precursor data indicate an even more pessimistic picture of historical trends (i.e. moderate increases in NMHC and substantial increases in NO_x from 1974 to 1978).

The historical emission trends are entered into the EKMA isopleth model to predict historical ozone trends; the predicted trends are then compared to actual ozone trends. Predicted ozone trends change very little from 1974 to 1978 (except for a slight increase from 1976 to 1977). For most sites/indices, actual ozone trends show little net change from 1974 to 1978, although there are significant fluctuations within the 4-year period. Most of the discrepancies between predicted and actual trends can be explained by the large error bounds in the analysis (e.g. uncertainty in the emission trend estimates and meteorological variance in the actual ozone trends). It is concluded that historical emission changes in Houston were not large enough from 1974 to 1978 to provide a definitive test of the EKMA isopleth method.

Although this study of historical trends in Houston is unable to provide a definitive test of the EKMA method, it does provide a better understanding of the emission and air quality effects being produced by control programs and source growth in the Houston region. In particular, this study explains an apparent paradox noted by previous researchers -- the lack of an ozone decrease from 1974 to 1978 in light of expected sizeable reductions in hydrocarbon emissions. There is no paradox; hydrocarbon emissions did not decrease significantly from 1974 to 1978 because rapid source growth negated the effects of controls and because many of the controls were installed prior to the 1974-1978 period.

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CHAPTER 1

INTRODUCTION AND SUMMARY

The Empirical Kinetic Modeling Approach (EKMA) has recently been proposed as a method for evaluating ozone control strategies (Dimitriades 1977a, EPA 1977, 1978, 1980). Before the EKMA method is accepted as a reliable technique for control strategy analysis, it should be subjected to validation studies. The purpose of this report is to test the EKMA method using historical trend data for the Houston area. Specifically, nonmethane hydrocarbon (NMHC) and nitrogen oxide (NO_x) emission trends in Houston are estimated for the years 1974 to 1978; these emission trends are entered in the EKMA method to predict historical ozone trends; the predicted ozone trends are then compared to actual ozone trends as a test of the EKMA method.

The historical trend data presented herein are not only of interest with respect to testing EKMA but also of interest in-and-of themselves. By conducting a detailed analysis of precursor (NMHC and NO_x) emission trends, we can show how emissions for individual source categories have changed due to controls and source growth, and how total emissions have responded to trends for individual source categories. By examining trends in ambient NMHC and NO_x data, we can check our emission trend estimates with an independent measure of precursor trends. By analyzing historical ozone trends, we can investigate whether or not the ozone trends make sense in light of precursor changes and meteorological fluctuations. Thus, this study is useful not only as a means to validate EKMA, but also as a means to understand the air quality effects actually being produced by control programs and source growth in the Houston region. In particular, this study has been able to explain an apparent paradox (Tannahill 1976; Radian 1977; HAOS 1979) involving the lack of an ozone decrease from 1974 to 1978 in light of expected sizeable reductions in hydrocarbon emissions. The answer is that hydrocarbon emissions did not decrease significantly from 1974 to 1978 because rapid source growth negated the effects of controls and because many of the controls were installed prior to the 1974-1978 period.

THE EKMA METHOD

The EKMA method for evaluating ozone control strategies is based on an isopleth diagram relating ozone levels to initial concentrations of NMHC and NO_x (see for example, Figure 27 on page 65). The ozone isopleth diagram is generated by a chemical-kinetic model calibrated to smog chamber data. The chemical-kinetic model has the capability to consider various irradiation times, dilution rates, solar insolation profiles, emission profiles, hydrocarbon composition mixes, and levels of transported ozone.

The EKMA isopleth diagram is not intended to be used in an absolute sense, i.e. to predict specific afternoon ozone levels for specific morning precursor concentrations. Rather, the EKMA isopleths should be used in a relative sense for control strategy evaluation, i.e. to predict changes in ozone levels for given percent changes in precursor emissions. The procedure for control strategy analysis with EKMA is essentially to locate base year coordinates on the isopleth diagram by specifiying the base year ozone level and NMHC/NO_x ratio, and to predict ozone for future years by factoring the NMHC and NO_x coordinates of the base year according to future emission changes.

Since the EKMA method is intended for use in a relative sense to estimate the sensitivity of yearly ozone levels to changes in yearly precursor emissions, the most appropriate validation tests for the method should involve historical trend data. Specifically, the EKMA isopleth method can be tested by using it to predict historical ozone trends based on historical precursor changes, and by comparing these predictions to actually observed ozone trends. Trijonis and Hunsaker (1978) and Trijonis and Mortimer (1981) conducted validation studies of the EKMA method using historical data for several sites in the Los Angeles region. To gain further insights into the ability of EKMA to predict historical ozone trends, the present report conducts validation studies using data for the Houston area.

THE HOUSTON STUDY AREA

There are two basic reasons why Houston was selected for the study region. First, as evidenced by the Houston Area Oxidants Study sponsored by the Chamber of Commerce and by several Houston programs sponsored by EPA, a great deal of interest currently exists in the Houston ozone problem. Second, substantial changes in historical precursor emissions are required for an adequate test of the EKMA method; previous investigations (Tannahill 1976; Radian 1977) suggest that large reductions in NMHC emissions, on the order of 20 to 35%, have occurred in the Houston area since 1974.

In this study, actual ozone trends are determined from data at two Houston monitoring stations, Mae Drive and Aldine (see Figure 7 on page 20 for the station locations). The investigation covers the years 1974 to 1978 at Mae Drive and 1975 to 1978 at Aldine. These are the only years for which complete smog season ozone data are available at the two locations.

Emission trends are compiled herein for 26 NMHC source categories and 15 NO_x source categories on a year by year basis from 1974 to 1978. The emission trend study region consists of Brazoria, Galveston, and Harris counties (see Figure 14 on page 30 for a map). Emission trends are determined for the entire study region and individually for five sub-areas of the region: Brazoria County, Galveston County, Ship Channel area of Harris County, Houston city area of Harris County, and remainder of Harris County. Because of reasons discussed in the text, emission changes for Harris County only are used in the isopleth validation tests for Mae Drive and Aldine.

A surprising conclusion of our emission trend analysis was that NMHC emissions did not change greatly in Houston from 1974 to 1978.[*] For example, our estimates indicate that Harris County NMHC emissions decreased 13% from 1974 to 1976 and then increased 16% from 1976 to 1978, so that there was little net change from 1974 to 1978. There was a moderate change in NO_x emissions; our calculations show that Harris County NO_x emissions grew by 22% from 1974 to 1978. Considering the potential errors in our analysis, we found that these emission changes were not large enough to provide a definitive test of the EKMA method.

Despite the fact that historical emission changes were too small to provide an adequate test of the EKMA method, this study was fruitful in supplying a great deal of interesting information regarding the ozone problem in Houston. The study contains an extensive investigation of historical/seasonal/diurnal/meteorological patterns in ambient ozone data and a thorough analysis of historical NMHC and NO_x trends (using both emissions data and ambient precursor data).

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[*] The reason for the disagreement between our conclusions concerning NMHC emission trends and previous conclusions by Tannahill (1976) and Radian Corporation (1977) are discussed at the end of Chapter 5.

SUMMARY

The purposes of this study are to gain a fundamental understanding of ozone phenomena at Mae Drive and Aldine by examining temporal ozone patterns and ozone/wind relationships (Chapter 2); to determine historical trends in NMHC and NO_x emissions in Houston resolved on a yearly basis, for various sub-areas, and for all major source categories (Chapter 3); to characterize historical ozone trends at Mae Drive and Aldine (Chapter 4); and to test the EKMA isopleth model by comparing predictions of historical ozone trends with actual ozone trends (Chapter 5). The following subsections summarize our findings and conclusions. For convenient referral, the summary is organized according to the order of the chapters.

Phenomenological Analysis of Ozone and Wind Data (Chapter 2)

- As expected, ozone levels tend to be higher at Aldine (located as a downwind receptor site for Houston air pollutants) than at Mae Drive (located near the major source areas). For both locations, the seven months April-October comprise a distinct "smog season" that is conducive to elevated ozone concentrations.
- The most salient characteristic of the ozone/wind relationship at both Mae Drive and Aldine during the smog season is the association of high ozone with calm winds. Another important feature of the ozone/wind relationship at both locations is the association of high ozone with transport from either the Houston City area or the Ship Channel area.
- The daily ozone maximum is most likely to occur from 12 AM to 4 PM at Mae Drive and 1 PM to 5 PM at Aldine. Assuming that solar irradiation effectively begins at 8:00 AM, the mean irradiation times up to the ozone peak during the smog season are 6 1/4 hours at Mae Drive and 6 3/4 hours at Aldine. On days of extreme ozone, the mean irradiation time is approximately 7 hours at both locations.

Historical Emission Trends (Chapter 3)

- Emission trends are determined by three factors: uncontrolled emission levels, growth of source activity levels, and the timing and effectiveness of controls. Each of these three factors often involves considerable uncertainty. To help minimize these uncertainties, we have attempted to use the most accurate and up to date information available from industrial representatives, consulting firms, trade associations, and local/state/federal agencies. Despite our efforts, certain information gaps persist which lead to significant uncertainties in our emission trend estimates.

- Estimated emissions of NMHC in the three-county study region decreased 17% from 1974 to 1976 and increased 12% from 1976 to 1978, so that only a slight NMHC reduction (7%) occurred from 1974 to 1978. The single major source category undergoing a significant reduction in NMHC from 1974 to 1978 was the chemical industry which, despite extremely rapid growth in output, managed to decrease NMHC emissions by 34%. Although some degree of control was installed on all other major NMHC source categories from 1974 to 1978, these controls were insufficient to overcome growth rates; thus, NMHC emissions from motor vehicles, the petroleum industry, and other sources all increased slightly from 1974 to 1978. The two major reasons for the lack of significant NMHC reductions in the Houston region from 1974 to 1978 were rapid source growth and the fact that most of the stationary source controls were already in place by 1974.

- The regionwide 7% decrease in NMHC emissions from 1974 to 1978 was composed of a 34% decrease in Brazoria County, a 13% decrease in Galveston County, and a 1% increase in Harris County. Brazoria County experienced a significant decrease in NMHC because the chemical industry (which was controlled during the period) is of great relative importance there.

- Estimated emissions of NO_x in the three-county region rose by 18% from 1974 to 1978. The NO_x increase was a product of high growth and the absence of NO_x controls (except for automobiles). The predominant part of the NO_x rise resulted from a 43% increase in chemical industry NO_x over the four years. Increases in NO_x from other sources were as follows from 1974 to 1978: petroleum industry -- 13%, power plants -- 15%, motor vehicles -- 7%, and all other sources -- 13%. The increase in NO_x emissions from the chemical and petroleum industries would have been substantially greater were it not for a voluntary fuel conservation program that significantly decreased fuel use per pound of product.

- The regionwide 18% increase in NO_x consisted of a 20% rise in Brazoria County, a 7% rise in Galveston County, and a 22% rise in Harris County. The Ship Channel area of Harris County experienced an especially large increase in NO_x (45% over the four years) due to growth in the chemical and petroleum industries.

- Trends in ambient precursor data at Mae Drive and Aldine present a more pessimistic picture than our emission trend data. The ambient data indicate that NMHC concentrations increased somewhat (on the order of 7 to 23%) and NO_x concentrations increased substantially (on the order of 16 to 48%) from 1974 to 1978. It should be noted, however, that the ambient trend data (like the emission trend data) also involve significant uncertainties.

Historical Ozone Trends (Chapter 4)

- Complete smog season ozone data are available for 1974-1978 at Mae Drive and 1975-1978 at Aldine. Considering the entire historical record, no overall trends are evident in the ozone data. The only exception is the yearly second maximum hourly concentration at Aldine which displays a significant decrease from 1975 to 1978.

- Meteorological normalization of the ambient ozone trends should eliminate weather biases in the trends and should reduce the statistical error bounds on the trends. In a companion study, however, Zeldin (1979) encountered several fundamental difficulties with meteorological normalization techniques that precluded their application to the Houston ozone data. Further research into meteorological adjustment procedures is necessary before such procedures can be used in practice.

- Stratification of the historical ozone trends by wind direction fails to reveal any consistent patterns at Mae Drive or Aldine. Because of the limited number of data points for given wind directions, the wind-stratified trend data appear to be dominated by large stochastic fluctuations from year to year.

Validation of the EKMA Isopleth Method (Chapter 5)

- In the validation studies, historical emission trends and the standard EKMA isopleth model are used to predict historical ozone trends; these predicted trends are then compared to actual ozone trends. The tests are conducted from 1974 to 1978 at Mae Drive and 1975 to 1978 at Aldine using two ozone air quality indices: the 95th percentile of daily maxima during the smog season, and the yearly second maximum hourly concentration.

- Because the emission changes during the study period were rather small, and because NMHC and NO_x emissions underwent rather similar variations from 1975 to 1978, the predicted ozone trends are insensitive to the initial NMHC/NO_x ratio (ratios of 8.5:1, 17:1, and 47:1 are used in the tests). The two major sources of error in the analysis are uncertainties in the emission trend estimates and (especially) statistical errors in the ambient ozone trends caused by yearly weather fluctuations.

- **Predicted ozone trends show little change from 1974 to 1976, a slight increase from 1976 to 1977, and little change from 1977 to 1978.** For both air quality indices at Mae Drive and for the 95th percentile of daily maxima at Aldine, actual ozone trends increase moderately in 1975 and/or 1976 and then decrease somewhat in 1977 and 1978. The net result for these three cases is that the isopleth model underpredicts ozone somewhat in 1975 and/or 1976 but yields fairly good agreement in 1977 and 1978. The discrepancies could easily be explained by potential errors in the emission trends and by meteorological variance in the actual ozone trends. In the fourth case, yearly second maximum ozone at Aldine, actual ozone underwent a substantial **decrease from 1975 to 1978, producing a large discrepancy with predicted trends. The large discrepancy might be explained by the very anamolous behavior of this particular air quality index at Aldine (i.e. by an extreme statistical error in this air quality index at Aldine).**

- Given the rather large error bounds in our analysis, it is difficult to tell if there is any fault with the EKMA model itself. In fact, a major finding of this study is that emission changes in Houston from 1974 to 1978 were not large enough to provide an adequate test of the EKMA model.

- Previous investigators (Tannahill 1976; Radian 1977) have noted an apparent paradox in the sense that ozone levels increased somewhat at Mae Drive and Aldine from 1974 to 1976, a period in which hydrocarbon emissions were supposedly reduced by about 20 to 35%. Our analysis helps to explain this paradox. For one, the ozone increase from 1974 to 1976 seems to have been a temporary fluctuation (ozone levels came back down in 1977 and 1978); also, the NMHC emission decrease was not as much as expected (12% in Harris County and 17% in the three-county study region from 1974 to 1976).

CHAPTER 2

PHENOMENOLOGICAL ANALYSIS OF OZONE AND WIND DATA

Before proceeding with the Houston validation study of the EKMA isopleth model, it is worthwhile to conduct a general phenomenological analysis of ozone and wind data at Mae Drive and Aldine. Such analysis will help provide an overall understanding of ozone air quality at the Houston study sites. Furthermore, it will allow us to attain the specific objectives of selecting a "smog-season" for the study, determining source areas affecting the monitoring sites, and quantifying typical irradiation/transport times for peak ozone concentrations.

The data used in this chapter consist of hourly ozone and wind data for Mae Drive and Aldine during the years 1975-1977. The analysis methods include seasonal plots, diurnal plots, wind roses, and pollution roses that illustrate the salient features of the ozone and wind data as well as their interrelationships.[*]

SEASONAL PATTERN OF OZONE CONCENTRATIONS

Figures 1 and 2 illustrate the seasonal pattern in ozone concentrations at Mae Drive and Aldine in terms of monthly averages of daily maximum 1-hour ozone concentrations (Figure 1) and monthly frequencies that daily maximum 1-hour ozone exceeds given thresholds (Figure 2).[**] These figures reveal that there is a distinct "smog-season" conducive to elevated ozone

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[*] The TACB has very recently noted the existence of severe problems with the quality of the wind directional data at Mae Drive from 1975 to 1977 (Schroeder 1980). The data for 1975 may contain significant random errors due to the lack of quality control; the data for 1976 and 1977 appear to contain a directional bias of $+30^\circ$ (i.e. a 30° clockwise bias). In discussing wind data analyses at Mae Drive, our remarks will be tempered by references to this data quality problem.

[**] In order to avoid possible distortions produced by missing measurements, all ozone data reported in this chapter have been sorted to include only those days containing at least 6 reported hourly averages from 10:00 AM to 7:00 PM CDT. As will be demonstrated later, elevated ozone concentrations in Houston are confined almost exclusively to the 10:00 AM - 7:00 PM period.

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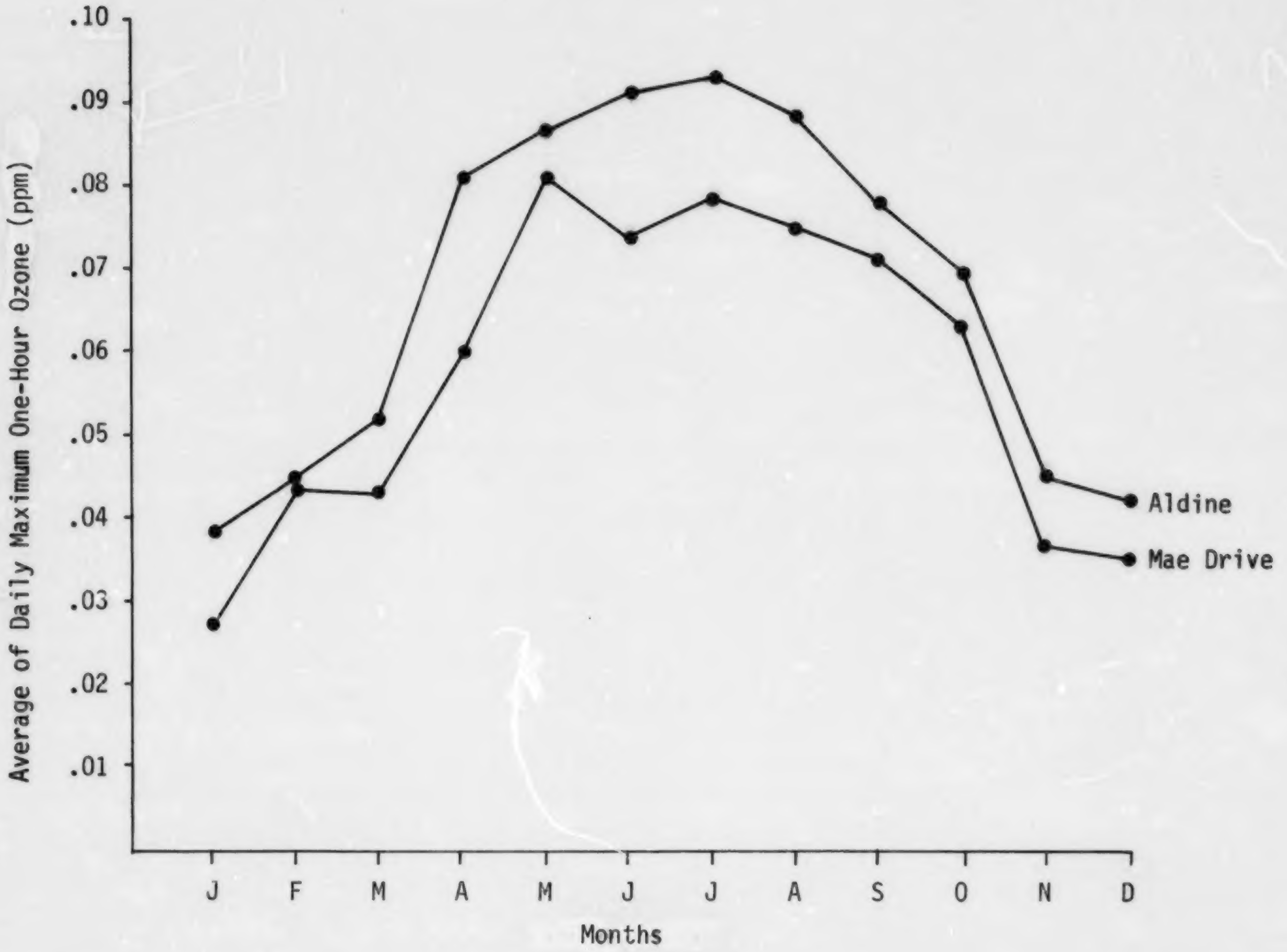


Figure 1 . Seasonal pattern of average daily maximum 1-hour ozone in Houston, 1975-1977.

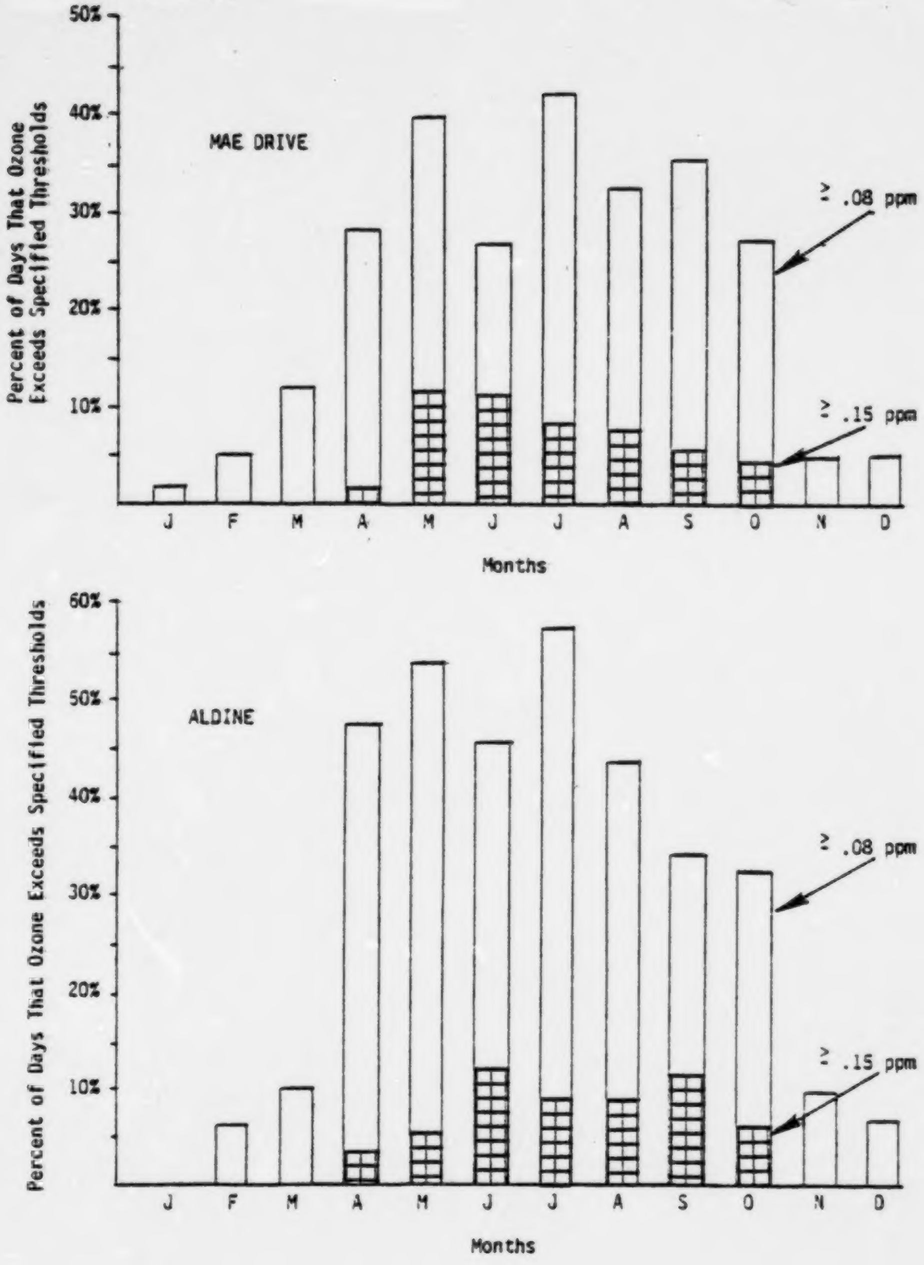


Figure 2. Seasonal pattern of the frequency that daily maximum 1-hour ozone exceeds given thresholds in Houston, 1975-1977.

concentrations in Houston. As demonstrated by Figure 1, each month from April to October experiences average daily maximum ozone concentrations exceeding .060 ppm at Mae Drive and .070 ppm at Aldine; conversely, each month from November to March exhibits daily maximum ozone concentrations of less than .044 ppm at Mae Drive and .052 ppm at Aldine. Furthermore, as shown in Figure 2, the April-October months contain 90% of the days when maximum 1-hour ozone exceeds .08 ppm and 100% of the days when maximum ozone exceeds .15 ppm. The tendency for high ozone concentrations during the summer months is, of course, a very typical phenomenon nationally and is due (at least in part) to increased photochemical activity resulting from more intense solar radiation and higher temperatures during the summer. The sharp demarcation between the high ozone months and low ozone months in Houston simplifies the selection of a photochemical smog season for that area; specifically, we will restrict the remainder of this study to the 7-month period, April-October.

Figures 1 and 2 illustrate another important aspect of Houston ozone air quality -- that ozone levels tend to be higher at Aldine than at Mae Drive. The Texas Air Control Board specifically selected Aldine as a downwind, receptor site for Houston air pollutants (TACB 1975). The higher ozone concentrations at Aldine reflect the fact that a certain amount of time (and therefore travel distance) is required for photochemical reactions to produce peak ozone. The station located near the major source areas (Mae Drive) tends to exhibit lower ozone because the photochemical precursors are often transported away from that site before peak ozone is produced and because the density of nearby emission sources may suppress ozone due to NO scavenging.

DIURNAL PATTERNS OF OZONE AND WIND

Figure 3 illustrates the average diurnal pattern of ozone concentrations at Mae Drive and Aldine during the April-October smog season. The averages for each hour (CDT) are plotted at the half-hour, i.e. the midway point of the hourly measurement. The diurnal patterns at both locations exhibit the expected pattern: very low ozone from 9:00 PM to 8:00 AM as the

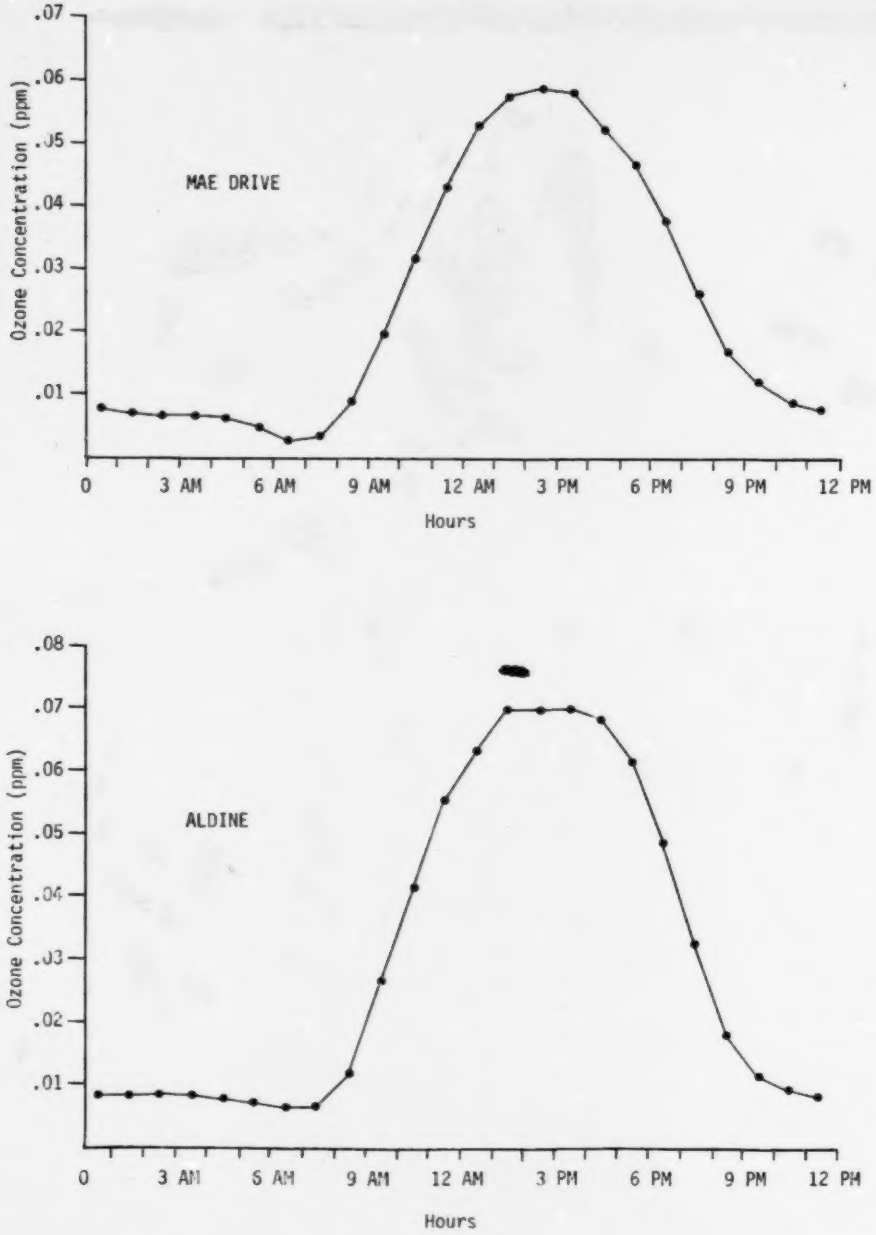


Figure 3. Diurnal patterns of hourly average ozone concentrations, (April-October, 1975-1977).

scavenging effect of NO emissions predominates during the absence of sunlight; increasing ozone during the late morning and early afternoon due to photochemical oxidant production from NO_x and RHC; an ozone peak during the middle afternoon; and decreasing ozone in the late afternoon and evening as NO scavenging again takes hold with waning sunlight and rush-hour NO emissions. The average ozone peak is higher at Aldine ($\sim$ .07 ppm) than at Mae Drive ($\sim$ .06 ppm) and occurs slightly later at Aldine ($\sim$ 1:30 - 4:30 PM) than at Mae Drive ($\sim$ 1:00 - 4:00 PM). The higher and later ozone peak at Aldine reflects the downwind, receptor nature of that site in contrast to the source-located nature of Mae Drive.

Figure 4 illustrates the diurnal pattern of ozone in terms of the percentage of hours exceeding two thresholds (.08 and .15 ppm). It is evident that the occurrence of ozone above these thresholds is almost exclusively restricted to the hours of 11:00 AM to 7:00 PM, with the highest frequencies occurring from 1:00 - 4:00 PM at Mae Drive and from 1:00 - 5:00 PM at Aldine.

Figures 5 and 6 present wind roses for Mae Drive and Aldine based on hourly, vector-averaged wind data for April-October. Each wind rose indicates percent of calms (hourly vector wind speed $\leq$ 1.5 mph), percent of hours with each wind direction, and average wind speed for each wind direction. One wind rose is presented for all hours, and eight wind roses (0 - 3 AM, 3 - 6 AM, ..., 9 - 12 PM) are used to illustrate the diurnal variation of wind patterns.

The wind patterns at Mae Drive and Aldine are fairly similar. The overall wind rose for each location shows a significant percentage of winds from all directions. The most favored directions for the raw wind data are S and SW at Mae Drive and SE and S at Aldine. Actually, if we corrected for the 30° directional bias in much of the Mae Drive wind data (see footnote on page 9), the wind rose at Mae Drive would tend to be even more similar to the wind rose at Aldine (i.e. it would also peak at the S or SE direction). Wind rose data available from the Houston International Airport also show that the greatest frequency occurs from S to SE.

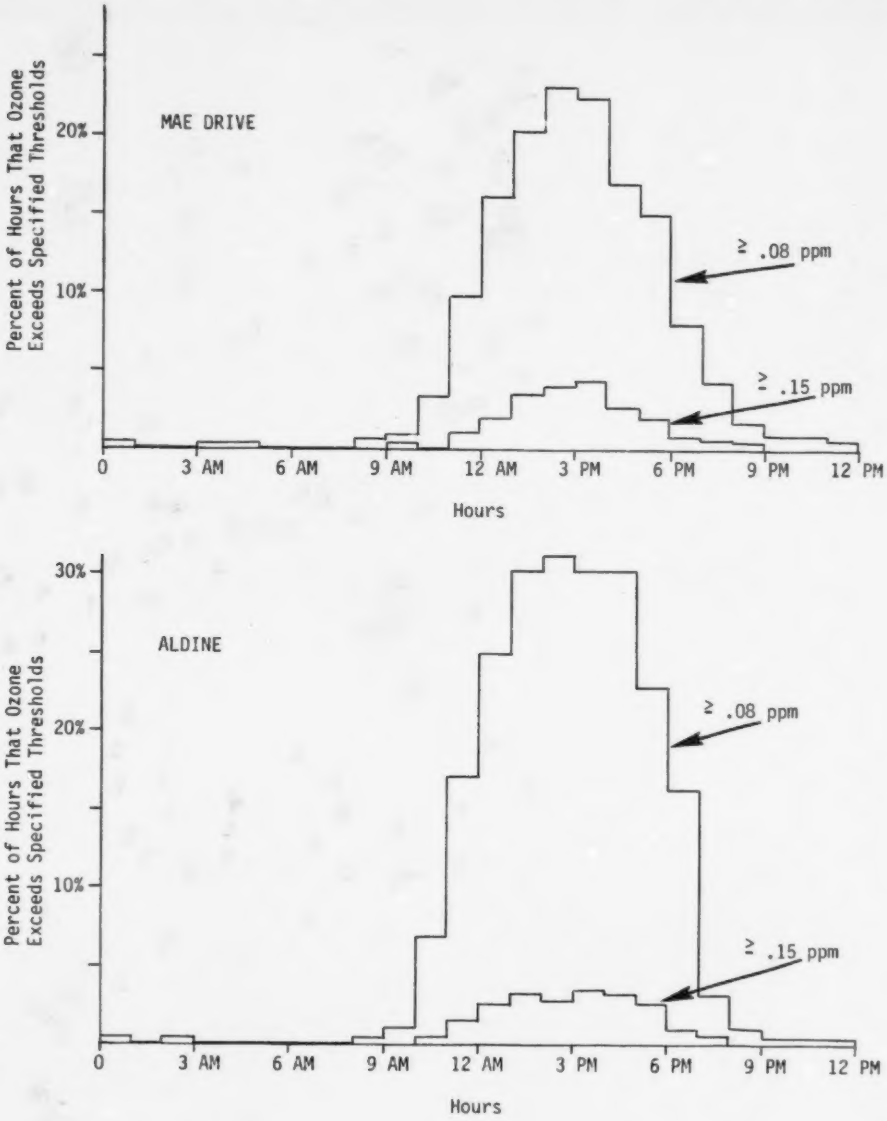
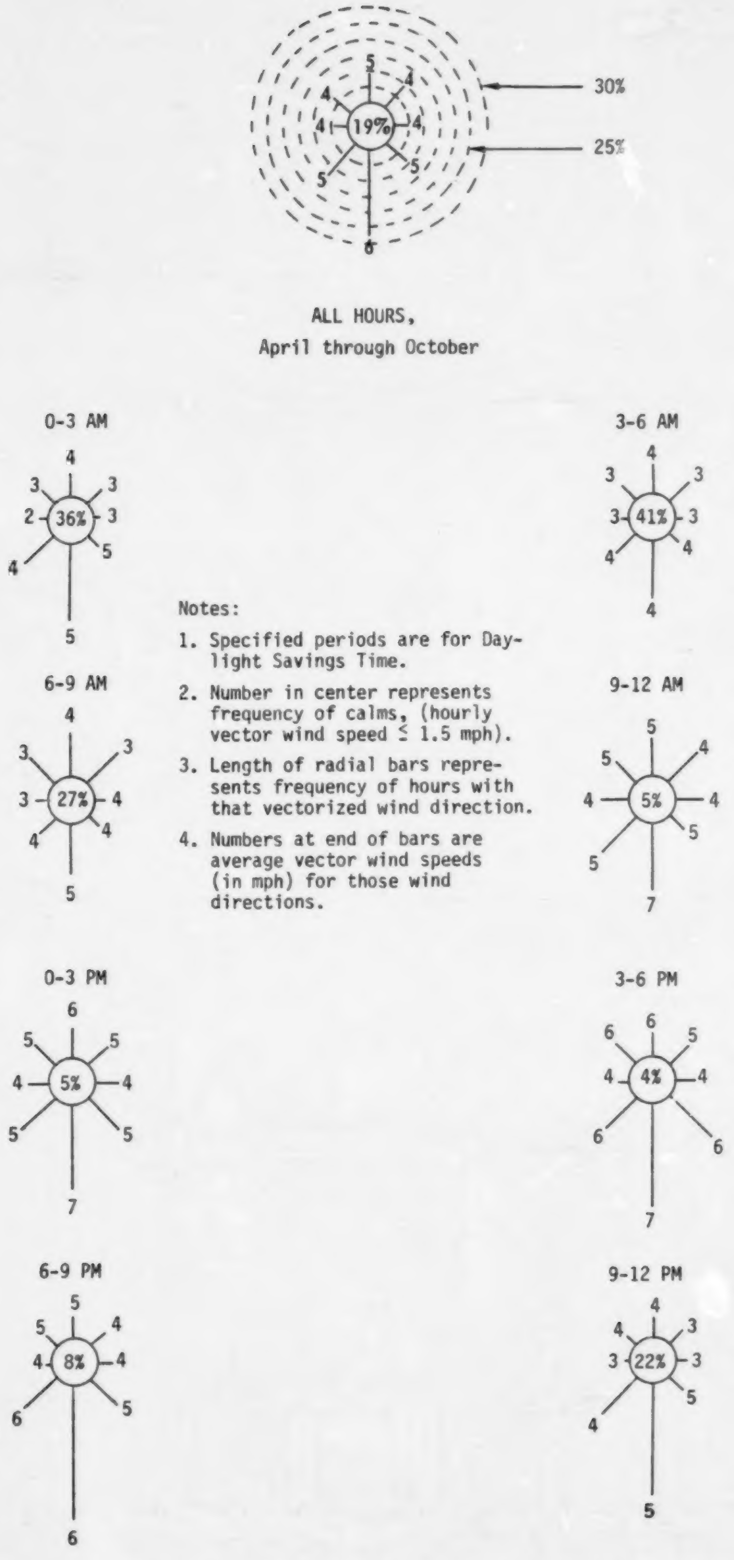


Figure 4. Diurnal patterns of frequency that hourly average ozone concentrations exceed given thresholds, (April-October, 1975-1977).



ALL HOURS,
April through October

0-3 AM

3-6 AM

6-9 AM

9-12 AM

0-3 PM

3-6 PM

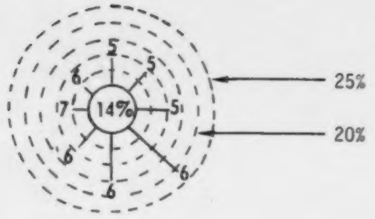
6-9 PM

9-12 PM

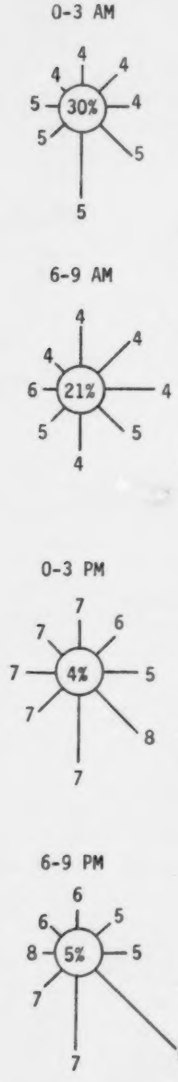
Notes:

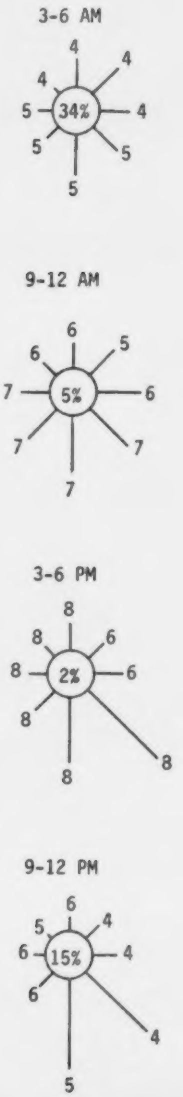
1. Specified periods are for Daylight Savings Time.
2. Number in center represents frequency of calms, (hourly vector wind speed ≤ 1.5 mph).
3. Length of radial bars represents frequency of hours with that vectorized wind direction.
4. Numbers at end of bars are average vector wind speeds (in mph) for those wind directions.

Figure 5. Wind roses of hourly vector-averaged wind data at Mae Drive, all hours and daily sub-periods, (April-October, 1975-1977).



ALL HOURS,
April through October





Notes:

1. Specified periods are for Daylight Savings Time.
2. Number in center represents frequency of calms, (hourly vector wind speed ≤ 1.5 mph).
3. Length of radial bars represents frequency of hours with that vectorized wind direction.
4. Numbers at end of bars are average vector wind speeds (in mph) for those wind directions.

Figure 5. Wind roses of hourly vector-averaged wind data at Aldine, all hours and daily sub-periods, (April-October, 1975-1977).

Calms are somewhat less frequent and average wind speeds are somewhat higher at Aldine than at Mae Drive. At both locations, there is a tendency for nocturnal stagnation -- frequencies of calms are notably high and wind speeds are notably low from 9:00 PM to 9:00 AM. At both locations, wind speeds rise rapidly after 9:00 AM and remain strong through the day and early evening. Although daytime transport exhibits significant components from all directions, the most prevalent directions are from the south or southeast.

In the next section, we will examine the relationship between daily peak ozone levels and wind transport conditions. In order to make this examination, a specific time period must be chosen for characterizing the wind transport vector each day. Based on the considerations that the morning rush-hour occurs before 9:00 AM, that transport winds become most significant after 9:00 AM, and that ozone tends to peak around 3:00 PM, we choose the 9:00 AM to 3:00 PM period as the appropriate time for calculating the wind transport vector each day.

RELATIONSHIP BETWEEN OZONE LEVELS AND WIND CONDITIONS

In order to identify the source areas most significantly affecting ozone levels at Mae Drive and Aldine, it is useful to examine the relationship between ozone concentrations and wind transport conditions. Specifically, we attempt to determine which wind directions are most conducive to high ozone concentrations. As one caveat to this analysis, we refer the reader to the footnote on page 9 concerning the problems with the Mae Drive wind directional data. As another caveat, it should be remarked that a correlation between high ozone levels and certain wind directions does not necessarily imply that the most significant source areas lie in those directions. Rather, the correlation may be a spurious one due to unaccounted for meteorological phenomena (e.g. certain wind directions may be associated with lower dispersion rates, more intense solar radiation, higher temperatures, etc.). Despite these caveats, however, we expect that the realtionship between ozone concentrations and wind direction should provide some insights concerning important source areas.

To assist in interpreting the relationship between ozone levels and wind directions, Figures 7 and 8 illustrate the location of principal source areas within the study region. Figure 7 delineates areas of low, moderate, and intense traffic; Figure 8 is an emission density map for major point sources of hydrocarbons. The area of most dense traffic centers around downtown Houston, while the major stationary source emitters are concentrated along the Houston Ship Channel and in Galveston and Brazoria Counties.

One way of investigating the relationship between ozone and wind conditions is to examine wind roses that are stratified by ozone levels. Figures 9 and 10 present, for Mae Drive and Aldine respectively, four wind roses of the daily transport wind vector (9 AM - 3PM): (1) for all days in the April-October smog season, (2) for days with maximum ozone < .08 ppm. (3) for days with maximum ozone ≥ .08 ppm but < .15 ppm, and (4) for days with maximum ozone ≥ .15 ppm. At both locations, the influence of wind speed is very apparent; higher ozone levels are obviously associated with more frequent calms and with lower wind speeds. The wind directional dependence at Mae Drive is rather subtle, perhaps reflecting quality problems with the Mae Drive wind direction data, and perhaps reflecting the fact that this site is nearly surrounded by major source areas (major stationary source emitters from the E to SW and major traffic areas from SW to NW). The wind directional dependence at Aldine is a very pronounced bimodal pattern; the highest ozone days have strong wind components in the SE and SW direction. This pattern seems to indicate that both Downtown Houston traffic and Ship Channel stationary emitters are important sources for Aldine ozone.

A second method of examining the relationship between ozone and wind conditions involves pollution roses, e.g. ozone levels plotted as a function of wind direction. Figures 11 and 12 present pollution roses for Mae Drive and Aldine (plotted on a linear scale rather than a circular scale to facilitate quantitative comparisons of the data). Pollution roses are presented both for average daily maximum ozone concentrations and for frequencies that daily maximum ozone exceeds given thresholds (.08 and .15 ppm).

For both Mae Drive and Aldine, ozone levels tend to be highest under calm conditions, again revealing the strong inverse relationship between

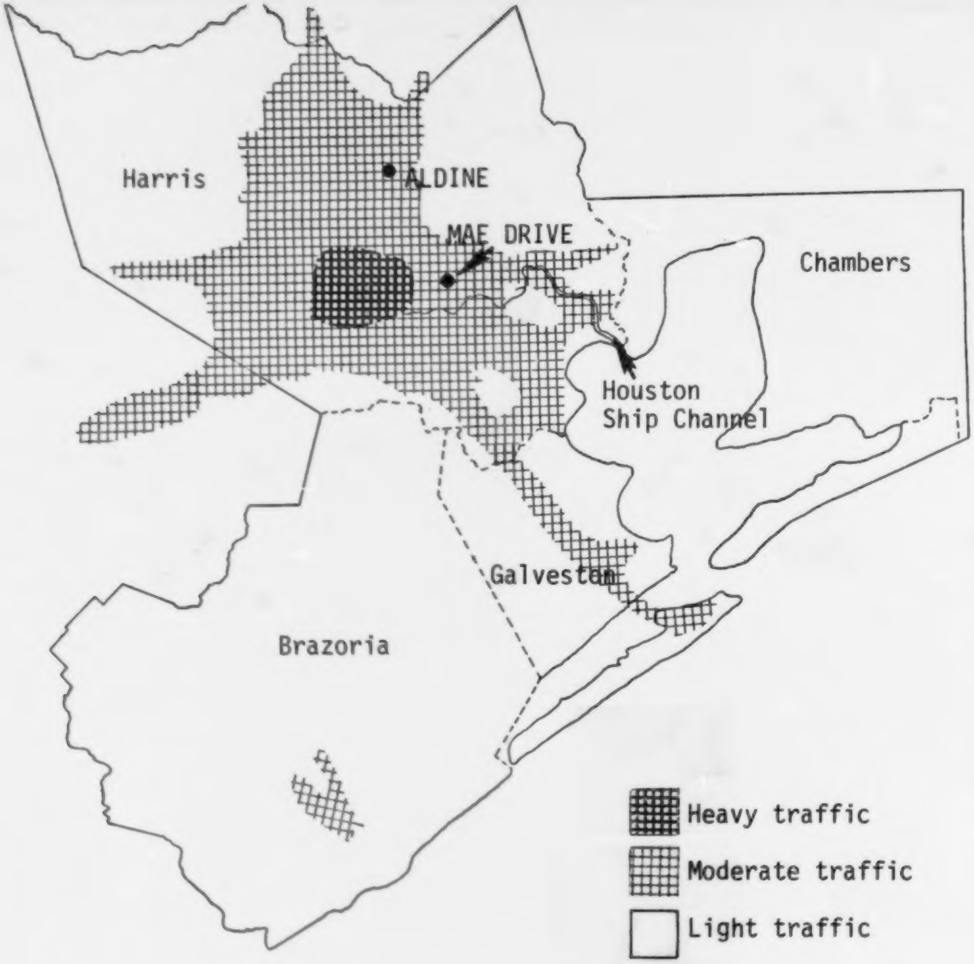

Harris
ALDINE
MAE DRIVE
Chambers
Houston
Ship Channel
Galveston
Brazoria
Heavy traffic
Moderate traffic
Light traffic

Figure 7. Approximate spatial distribution of traffic density in the Houston area (Houston-Galveston Regional Transportation Study, 1977).

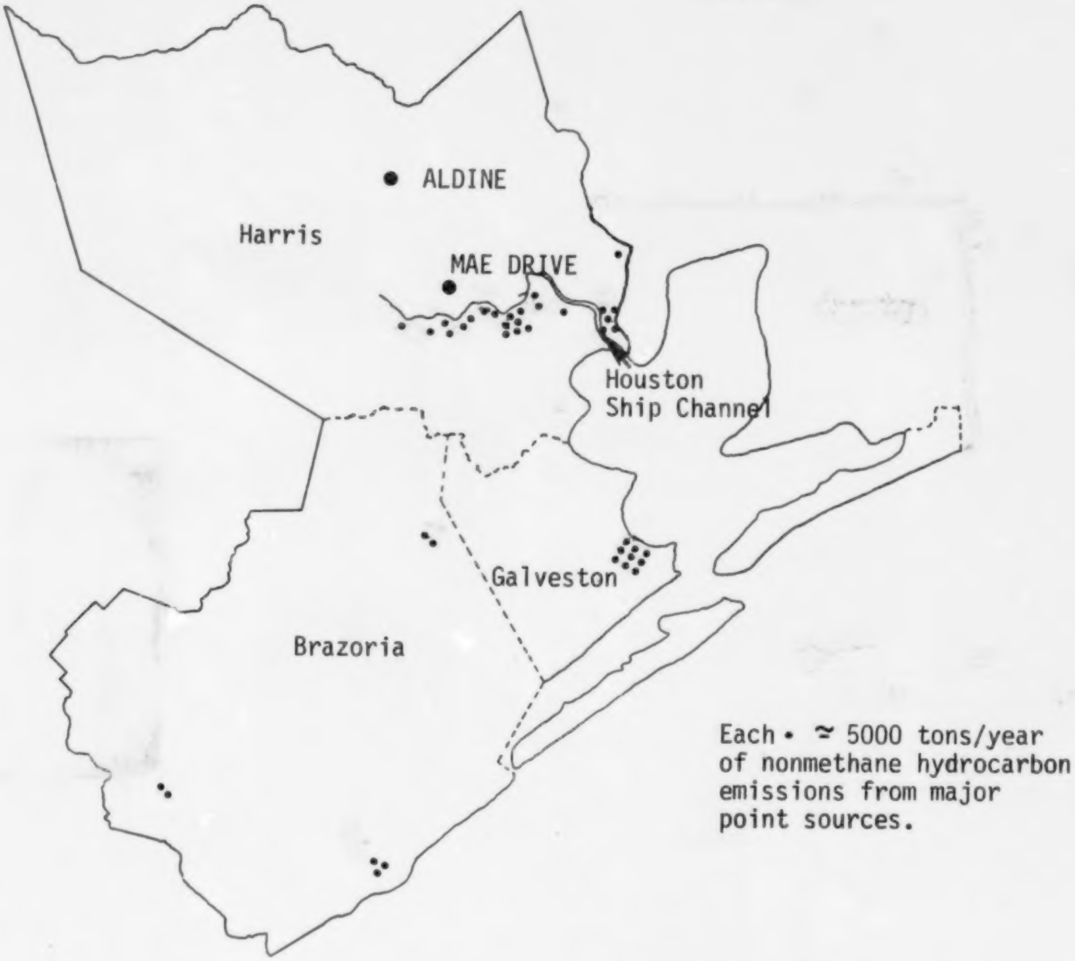
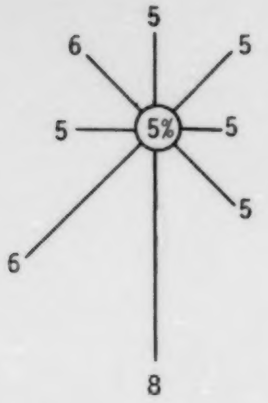
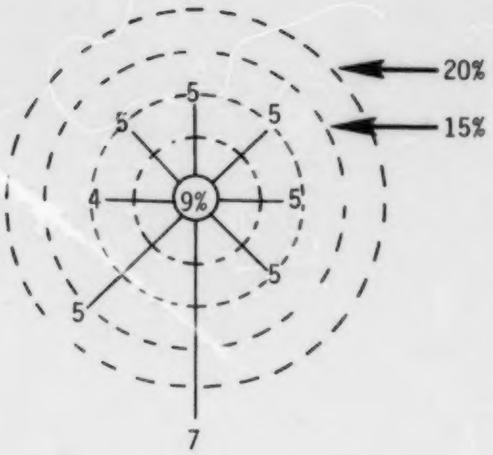

ALDINE
Harris
MAE DRIVE
Houston Ship Channel
Galveston
Brazoria
Each • ≃ 5000 tons/year of nonmethane hydrocarbon emissions from major point sources.

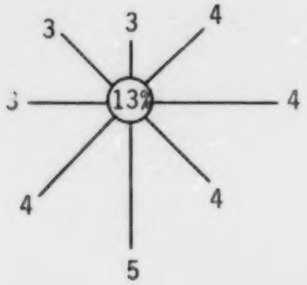
Figure 8. Approximate spatial distribution of hydrocarbon emissions from major point sources in the Houston area (Roeser 1980).



Days with maximum
ozone < .08 ppm



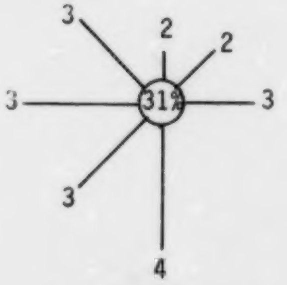
All Days



.08 ppm ≤ days with
maximum ozone < .15 ppm

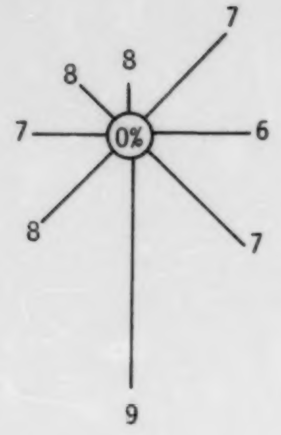
Notes:

1. Number in center represents frequency of calms, (6-hour vector wind speed ≤ 1.5 mph).
2. Length of radial bars represents frequency of hours with that vectorized wind direction.
3. Numbers at end of bars are average vector wind speeds (in mph) for those wind directions.

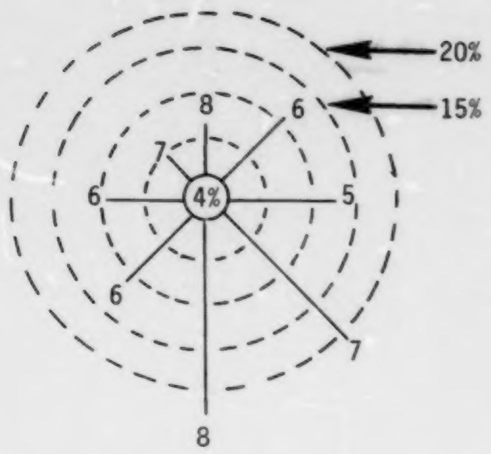


Days with maximum
ozone ≥ .15 ppm

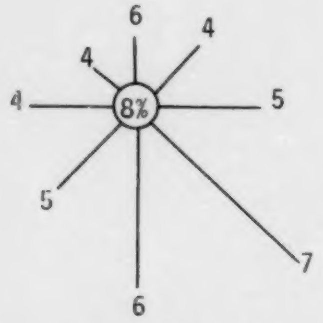
Figure 9. Wind roses for daily vector-averaged winds from 9 AM - 3 PM at Mae Drive, (April-October, 1975-1977).



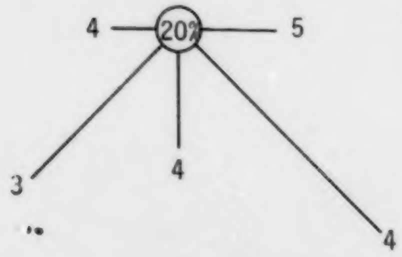
Days with maximum
ozone < .08 ppm



All Days



.08 ppm ≤ days with
maximum ozone < .15 ppm



Days with maximum
ozone ≥ .15 ppm

Notes:

1. Number in center represents frequency of calms, (6-hour vector wind speed ≤ 1.5 mph).
2. Length of radial bars represents frequency of hours with that vectorized wind direction.
3. Numbers at end of bars are average vector wind speeds (in mph) for those wind directions.

Figure 10. Wind roses for daily vector-averaged winds from 9 AM - 3 PM at Aldine, (April-October, 1975-1977).

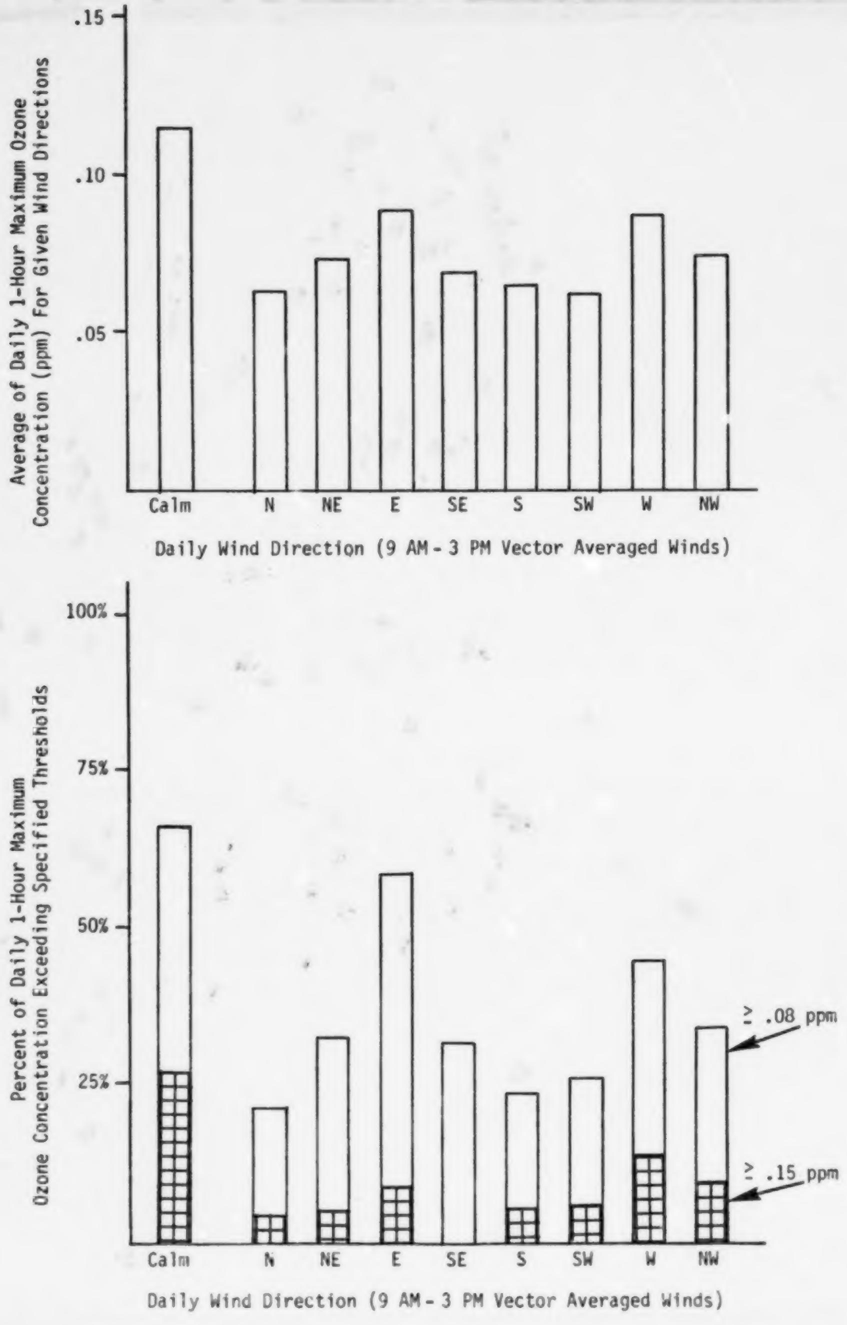


Figure 11. Daily 1-hour maximum ozone levels as a function of 9 AM - 3PM wind direction at Mae Drive, (April-October, 1975-1977).

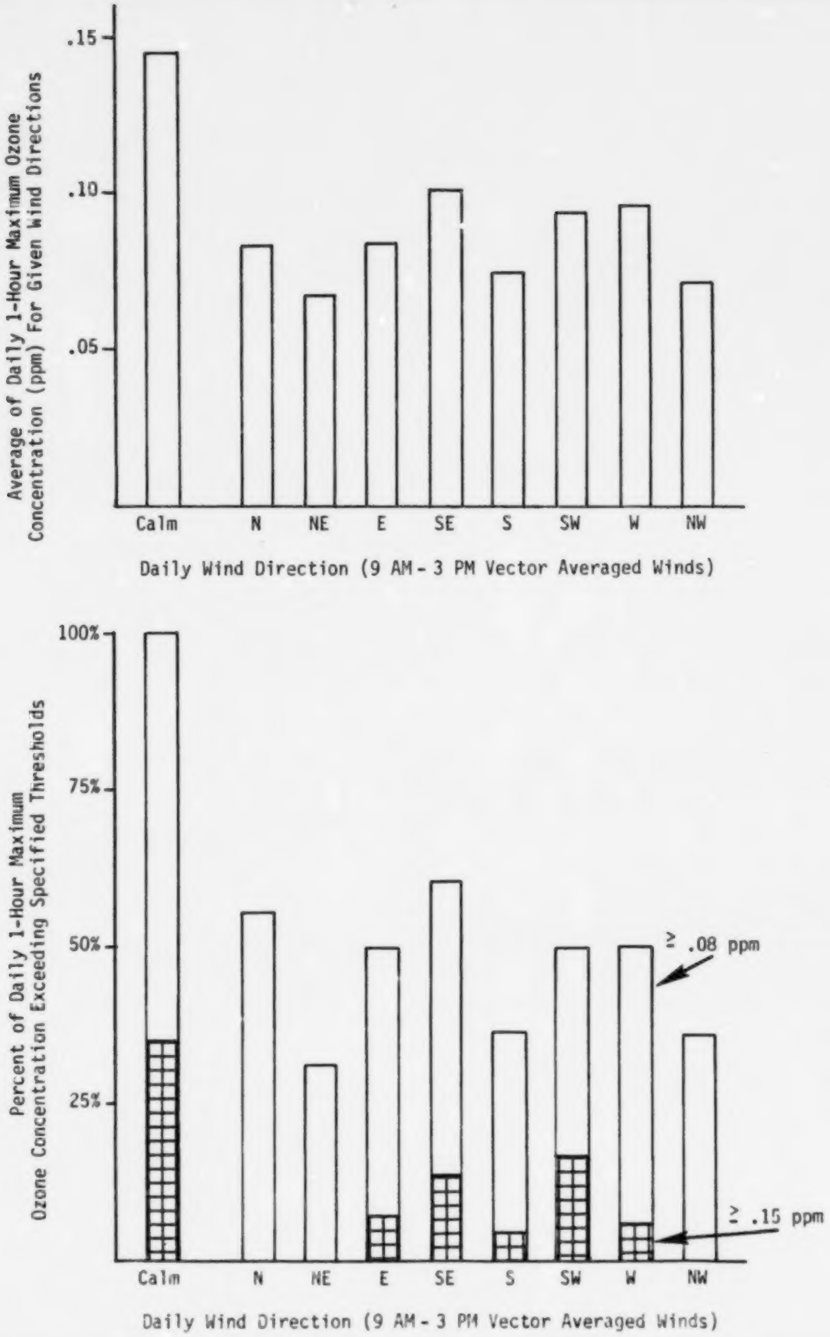


Figure 12. Daily 1-hour maximum ozone levels as a function of 9 AM - 3 PM wind direction at Aldine, (April-October, 1975-1977).

ozone and wind speed. The directional dependence of the pollution rose at Mae Drive indicates a double maximum, one peak to the west (toward the area of dense traffic around central Houston), and the other peak toward the east or northeast (possibly toward stationary source emissions along the length of the Ship Channel).* The pollution rose at Aldine demonstrates a triple maximum, one peak to the southeast (toward the Ship Channel), another peak to the southwest or west (toward the dense traffic area), and a tertiary peak (containing many days above .08 ppm but no days above .15 ppm) to the north (towards no obvious source area).

Although the above analysis must be tempered by the aforementioned caveats concerning the quality of the Mae Drive wind data and the possibility of spurious correlations between ozone concentrations and wind directions, it appears that the results make fairly good sense with respect to identification of important source areas affecting Houston oxidant. Later in this report (Chapter 3), the above results will serve as a basis for selecting specific source areas, so that the relevant emission trends can be computed for the isopleth validation study.

TIME OF THE OZONE MAXIMUM

In order to select appropriate EKMA isopleth models for the Houston validation studies,** it is necessary to know the irradiation times that correspond to peak ozone levels at Mae Drive and Aldine. Making the assumption that irradiation effectively commences at 8:00 AM CDT, the problem of determining irradiation times reduces to the problem of determining the time of the ozone peak.

Figure 13 illustrates the frequency distribution for the time of the daily one-hour ozone peak at Mae Drive and Aldine. At both locations, peak ozone almost always occurs between 11:00 AM and 6:00 PM CDT. The ozone peak

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*In arriving at this interpretation, we have made a slight correction for the +30° bias in much of the Mae Drive wind direction data (see footnote on page 9).

**The EKMA approach can yield isopleths for basinwide maximum ozone or for ozone at given reaction times (e.g. 5-hour, 7-hour, or 9-hour irradiations).

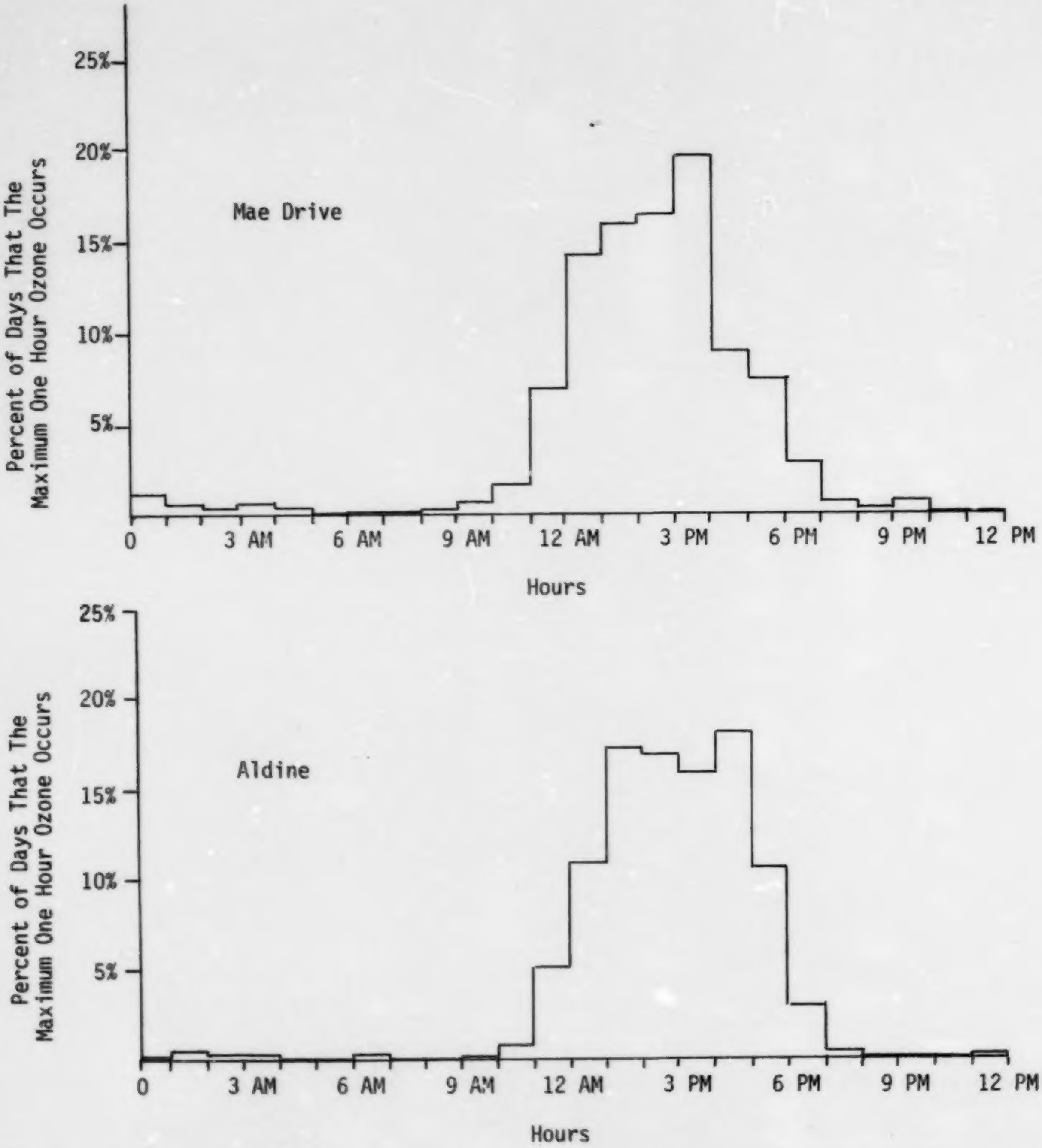

Figure 13. Frequency distribution of the time of occurrence for daily maximum ozone, (April-October, 1975-1977).

TABLE 1. MEAN TIME OF OCCURRENCE FOR MAXIMUM OZONE AS A FUNCTION OF THE MAGNITUDE OF THE OZONE PEAK.

LEVEL OF DAILY MAXIMUM ONE-HOUR OZONE	MEAN TIME OF OCCURRENCE FOR DAILY ONE-HOUR MAXIMUM OZONE MAE DRIVE	 ALDINE
Maximum Ozone < .08 ppm	1:50 PM	2:26 PM
.08 ppm ≤ Maximum Ozone < .15 ppm	3:03 PM	3:08 PM
.15 ppm ≤ Maximum Ozone	2:54 PM	3:07 PM

is especially probably during the hours of 12 AM - 4 PM at Mae Drive and 1 PM - 5 PM at Aldine. The mean time of occurrence of the one-hour ozone maximum[*] is 2:09 PM CDT at Mae Drive and 2:46 PM CDT at Aldine.

Because the EKMA isopleth validation study will focus on days of highest ozone levels, it is useful to determine if the time of the ozone peak depends substantially on the magnitude of the ozone peak. Table 1 indicates that, at both Mae Drive and Aldine, the ozone peak occurs at a slightly later time on days of highest ozone. For both locations, an ozone peak at 3:00 PM CDT seems characteristic of high ozone days.

Based on the above analysis, we conclude that the typical irradiation time (starting at 8:00 AM) is approximately 6 1/4 hours for Mae Drive and 6 3/4 hours for Aldine. For days of highest ozone, the typical irradiation time is approximately 7 hours at both locations. These conclusions will be referenced later when we select appropriate EKMA isopleth models for the Houston validation study.

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[*] In calculating the mean time for the ozone maximum, we assign the half-hour time to each hourly average (e.g. the 1:00 - 2:00 PM CDT hour is assigned the time of 1:30 PM CDT).

CHAPTER 3

HISTORICAL EMISSION TRENDS

The most difficult and time-consuming task in this study was the compilation of historical emission trends for the ozone precursors (NMHC and NO_x). Year-by-year emissions from 1973 to 1978 were determined for 26 NMHC source categories and 15 NO_x source categories using data obtained from research firms, industrial personnel, trade associations, and numerous federal/state/local government agencies. Appendix A, "Detailed Description of Emission Trend Calculations", discusses the data, assumptions, and methodology underlying the emission trend estimates.

Although the Houston-Galveston AQCR consists of 13 counties (see Figure 14), the study region for emission trends is restricted to only Brazoria, Galveston, and Harris Counties. These three counties contribute the dominant part (over 80%) of NMHC and NO_x emissions in the AQCR. Based on wind direction patterns (see Chapter 2) and the proximity of these counties to the Mae Drive and Aldine monitoring sites, we expect that these three counties account for the overwhelming part of man-made emissions in the AQCR that affect ozone at Mae Drive and Aldine. Emission trends are presented here for the study region as a whole and for five sub-areas of the region: Brazoria County, Galveston County, Ship Channel area of Harris County, Houston city area (excluding the Ship Channel area), and remainder of Harris County. These sub-areas are illustrated in Figure 14.

UNCERTAINTIES IN THE EMISSION TREND ANALYSIS

Before presenting our estimates regarding historical emission trends in Houston, it is worthwhile to briefly discuss uncertainties in the analysis. Our estimates of emission trends are essentially based on a multiplication of three factors: an uncontrolled emission factor for each source category, a source activity (growth) factor for each category and each year, and a control factor for each category and each year. As discussed in Appendix A, each of these factors involves uncertainty. The uncertainties vary considerably among source categories, with the greatest unknowns unfortunately

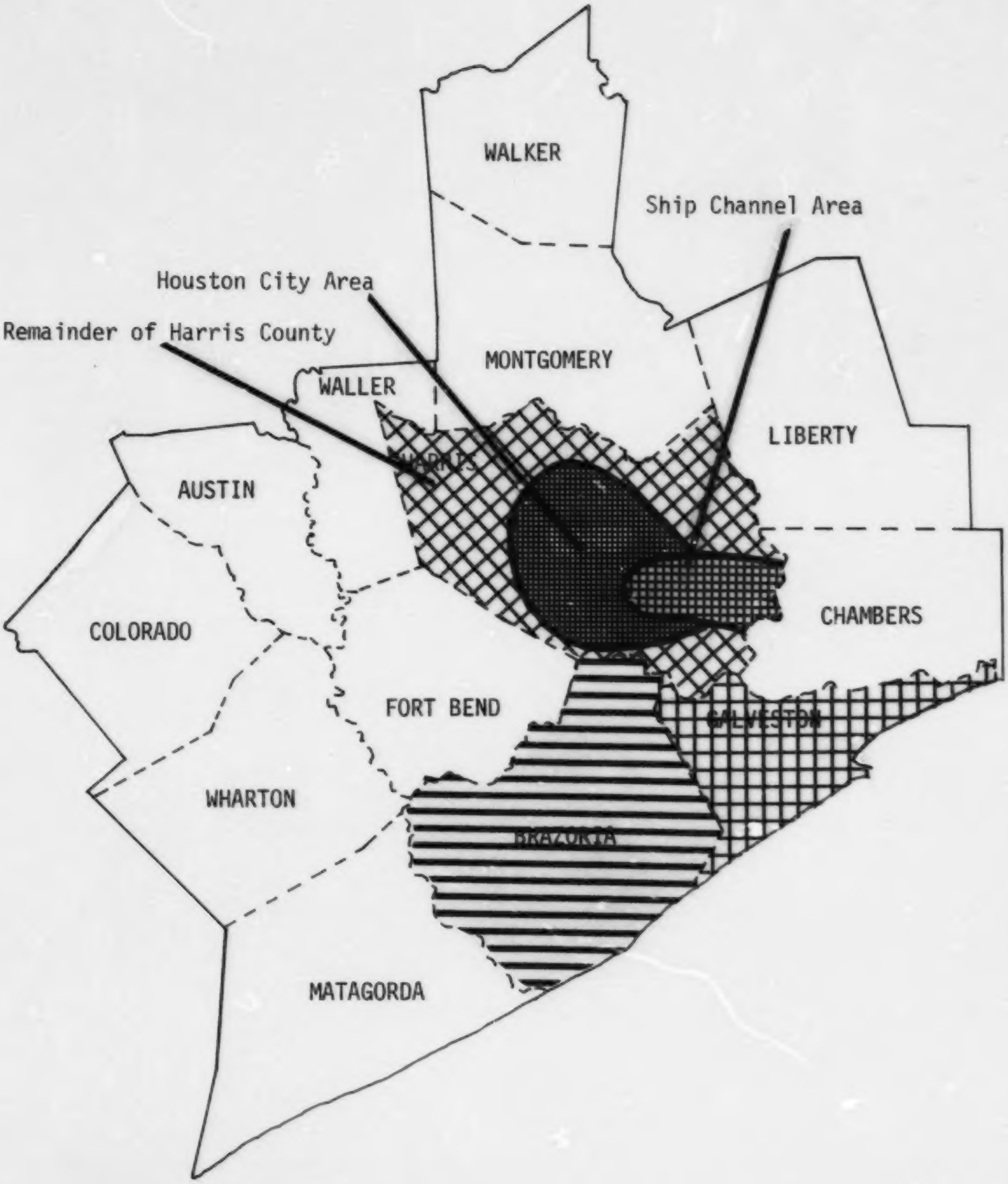
WALKER
Ship Channel Area
Houston City Area
Remainder of Harris County
MONTGOMERY
WALLER
LIBERTY
HARRIS
AUSTIN
CHAMBERS
COLORADO
FORT BEND
GALVESTON
WHARTON
BRAZORIA
MATAGORDA

Figure 14. Map of the Houston AQCR (shaded area is the study region).

associated with two of the dominant source categories -- the chemical industry and the petroleum industry.

Some of the uncertainties in our analysis were emphasized in discussions held with industrial representatives and TACB personnel after we presented preliminary results of this study at the APCA Specialty Conference on Ozone/Oxidants in October 1979. Among the new issues raised by industrial representatives and the TACB at that time were (1) that a conservation program on natural gas and other fuels made chemical and petroleum industry NO_x emissions increase less rapidly than throughput (Walker 1979); (2) that a voluntary tightening-up of hydrocarbon leaks reduced fugitive emissions in the chemical industry (Beck 1979); and (3) that our control schedules for the chemical and petroleum industries might be inaccurate (Stewart 1979). During the last phase of this project, we did considerable further work investigating these issues, revising our emission trend estimates, and re-working the isopleth validation studies. The changes we made included using the 1977 HAOS[*] inventory as a base year inventory, including the effects of a fuel conservation program in the chemical and petroleum industries, and using different data sources for production growth in the chemical industry. The comments made by industrial representatives and the TACB, as well as our responses to those comments, are discussed in detail in Appendix B.

In responding to various comments and re-working our emission trend estimates, we gained an even greater appreciation for the large uncertainties concerning historical emission trends in Houston, especially with respect to the petroleum and chemical industries. For this reason, we have placed fairly large error bounds on our emission trend estimates (see the last two sections of this chapter).

Our emission trend estimates may be controversial to some because they present a rather pessimistic conclusion regarding historical emission changes in Houston. We have found that, from 1974 to 1978, there was a slight reduction in hydrocarbon emissions (a decrease of 7%) and a moderate rise in NO_x emissions (an increase of 18%). It should be noted, however, that the ambient trend data for NMHC and NO_x yield even more pessimistic conclusions. As discussed in the last section of this chapter, we have found that ambient NMHC concentrations show a net increase on the order of 7 to 23% from 1974 to 1978, while ambient NO_x concentrations show a net increase on the order of 16 to 48% from 1974 to 1978.

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[*] Houston Area Oxidant Study

EMISSION TRENDS FOR THE ENTIRE STUDY REGION

Tables 2 and 3 present (for NMHC and NO_x respectively) emission trends for the entire study region, organized according to individual source categories. As explained in Appendix A, the emission trend calculations are even more detailed than evidenced by these tables. For example, petroleum and chemical processing include separate consideration of conventional and fugitive emissions; total vehicle NMHC emissions constitute both exhaust and evaportaion; source growth rates (e.g. traffic, petrochemical throughput, population, ...) and transportation factors are specific to each county; etc.

Figures 15 and 16 summarize the emission trends for NMHC and NO_x graphically. The top line in each figure represents total emission trends, while the distances between lines represent contributions from individual source categories. The points for 1973 are connected with dashed lines because only data for 1974 through 1978 will be used in the isopleth validation study (complete smog-season ozone data start in 1974 at Mae Drive and 1975 at Aldine).

As shown in Figure 15, regionwide NMHC emissions decreased by 15% from 1974 to 1975, decreased by 2% from 1975 to 1976, increased by 13% from 1976 to 1977, and decreased by 1% from 1977 to 1978. The basic reason for the downward jump from 1974 to 1975 was installation of controls in the chemical industry; the reason for the upward jump from 1976 to 1977 was rapid growth in the chemical and petroleum industries.

The net NMHC emission change from 1974 to 1978 was a reduction of 7%. This overall reduction basically resulted from the chemical industry which, despite significant growth in output, managed to decrease NMHC by 34% from 1974 to 1978. The controls on motor vehicles and the petroleum industry

TABLE 2. NMHC EMISSION TRENDS FOR THE ENTIRE STUDY REGION.

SOURCE CATEGORY	NMHC EMISSIONS (1000 TONS/YEAR)					
	1973	1974	1975	1976	1977	1978
STATIONARY POINT SOURCES						
Petroleum Industry						
Petroleum Refining	57.7	55.6	56.1	59.5	68.2	67.3
Refinery Storage	28.2	18.2	16.5	14.1	15.4	15.7
Crude Storage	2.3	1.7	1.2	1.1	0.9	0.9
Refinery Loading	8.7	8.1	8.7	8.6	10.3	10.4
Crude Loading	6.8	6.8	6.2	6.0	5.5	5.4
Natural Gas Processing	1.9	1.6	1.7	1.6	1.3	1.3
Chemical Industry						
Chemical Processing	133.7	126.2	71.3	58.7	84.1	76.5
Chemical Storage	15.4	11.0	8.2	8.9	11.9	12.7
Chemical Loading	1.4	1.3	1.2	1.4	2.1	2.1
Other Point Sources	13.4	13.7	14.2	14.6	15.1	15.5
STATIONARY AREA SOURCES						
Paving	1.4	1.4	1.6	1.7	1.8	1.9
Gasoline Marketing	9.1	9.0	9.7	10.4	11.2	11.9
Industrial Painting	4.7	4.9	5.1	5.2	5.3	5.5
Degreasing and Solvents	9.6	9.9	10.2	10.5	10.8	11.1
Drycleaning	2.4	2.4	2.4	2.4	2.4	2.4
Com/Res Painting	2.5	1.7	1.2	1.2	1.3	1.2
Fuel Burning	0.9	1.0	1.1	1.1	1.1	1.2
MOBILE SOURCES						
Motor Vehicles						
Passenger Cars	70.1	69.3	68.1	68.2	66.0	66.1
Light Duty Trucks	20.2	21.4	22.9	23.9	25.3	26.2
Heavy Duty, Gas	9.8	12.7	10.2	11.6	12.9	14.2
Heavy Duty, Diesel	0.3	0.4	0.5	0.7	0.7	0.8
Motorcycles	0.9	0.9	0.9	0.9	0.9	0.9
Off-Road Vehicles	2.9	3.0	3.1	3.3	3.4	3.4
Other Transportation						
Trains	0.9	0.9	0.9	0.9	0.9	0.9
Airplanes	1.6	1.7	1.8	1.9	2.0	2.2
Boats	2.5	2.5	2.5	2.6	2.7	2.8
TOTAL	409.3	387.3	327.5	320.9	363.5	360.5

TABLE 3. NO_x EMISSION TRENDS FOR THE ENTIRE STUDY REGION.

SOURCE CATEGORY	NO_x EMISSIONS (1000 TONS/YEAR)					
	1973	1974	1975	1976	1977	1978
STATIONARY POINT SOURCES						
Petroleum Refineries	42.5	41.8	44.8	45.1	48.9	50.5
Natural Gas Refineries	12.8	11.4	11.5	10.9	10.0	9.4
Chemical Industry	62.4	62.4	54.9	64.5	80.3	89.1
Power Plants	41.8	44.8	44.5	46.6	50.6	51.5
Other Point Sources	9.5	10.0	10.4	10.8	11.3	11.5
STATIONARY AREA SOURCES						
Fuel Burning	5.1	5.3	5.5	5.7	6.0	6.1
MOBILE SOURCES						
Motor Vehicles						
Passenger Cars	53.3	52.3	52.5	53.3	50.6	49.2
Light Duty Trucks	13.7	14.9	16.3	17.5	18.3	19.5
Heavy Duty, Gas	8.9	11.4	9,3	10.8	11.7	12.5
Heavy Duty, Diesel	2.7	3.1	4.1	5.3	5.5	6.2
Motorcycles	0.0	0.0	0.0	0.0	0.0	0.0
Off-Road Vehicles	7.2	7.5	7.7	8.0	8.2	8.4
Other Transportation						
Trains	3.6	3.6	3.6	3.6	3.6	3.6
Airplanes	1.1	1.2	1.3	1.4	1.5	1.6
Boats	3.7	3.8	3.9	4.0	4.2	4.2
TOTAL	268.3	273.5	270.3	287.5	310.7	323.3

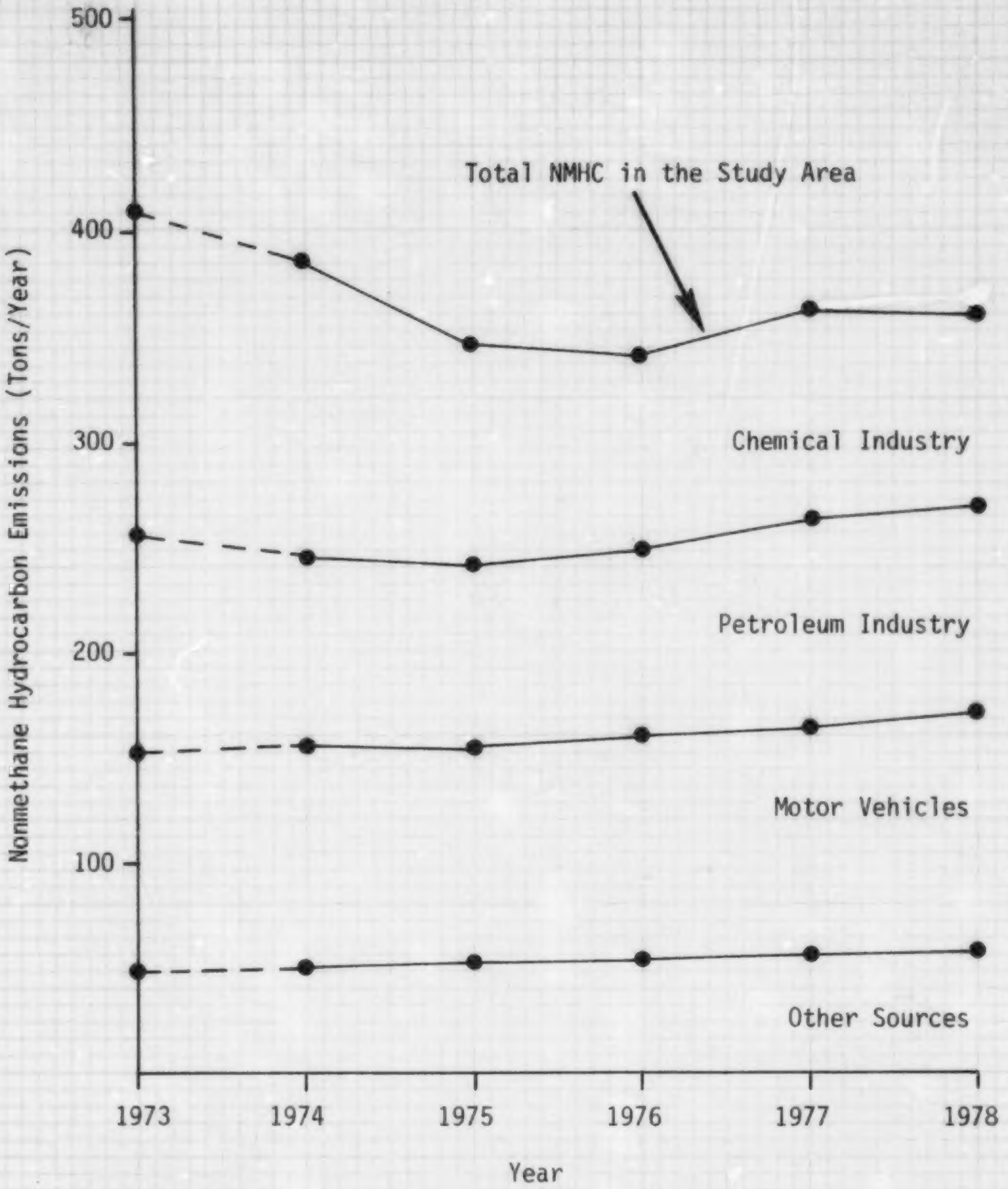

Figure 15. NMHC emission trends for the entire Houston study area.

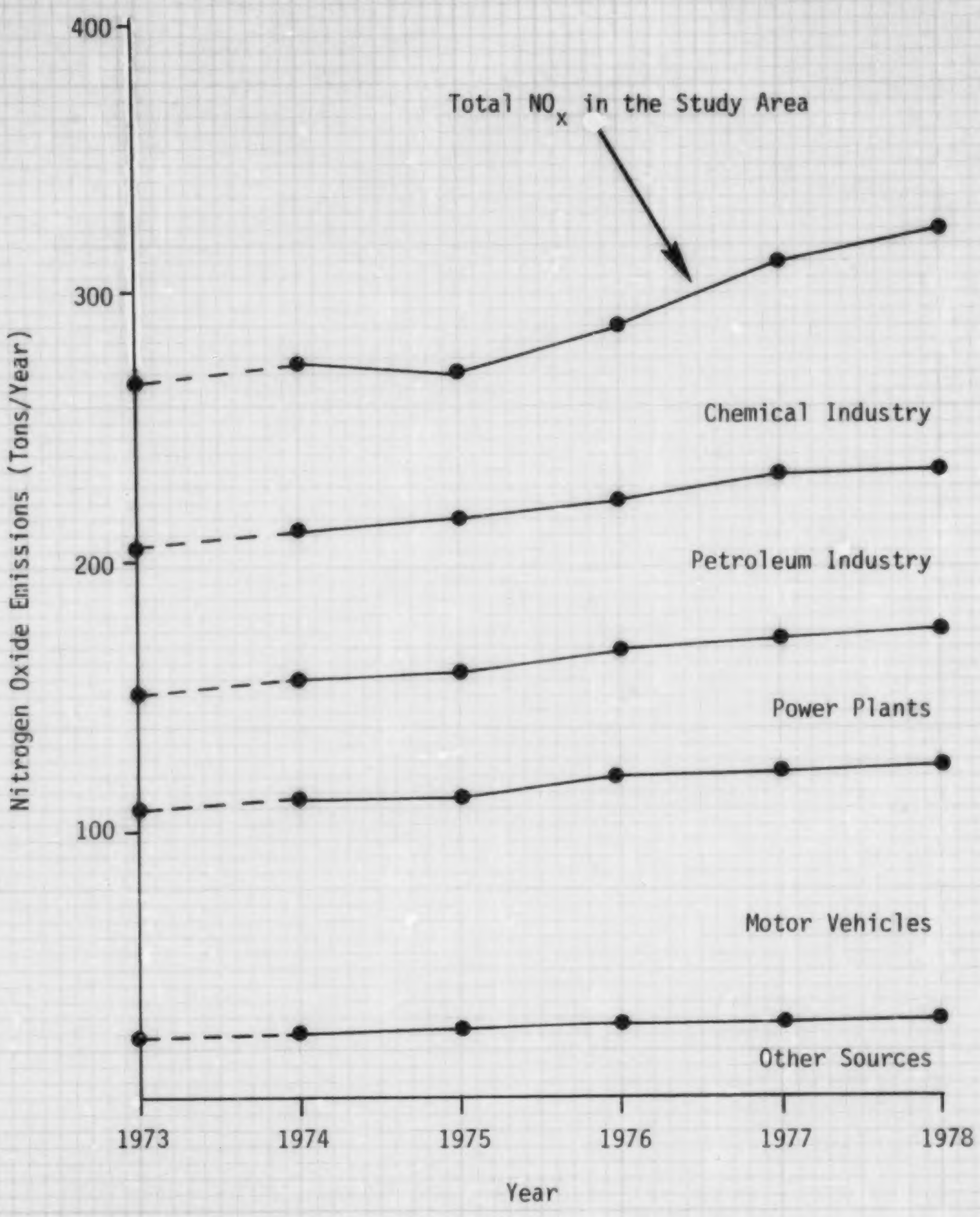

Figure 16. NO_x emission trends for the entire Houston study area.

were insufficient to overcome growth rates; from 1974 to 1978, NMHC from motor vehicles and the petroleum industry increased 4% and 10% respectively. The minor contributions from all other NMHC sources increased by 15% over the four years.

Figure 16 demonstrates that NO_x emissions increased by 18% from 1974 to 1978, with most of the rise occurring from 1975 to 1978 (especially 1976 to 1977). The greatest part of the NO_x increase resulted from a 43% rise in chemical industry NO_x over the four years. The petroleum-gas industry, power plants, and motor vehicles experienced NO_x increases of 13%, 15%, and 7%, respectively. The minor contributions from all other NO_x sources increased by 13% from 1974 to 1978.

More detailed expositions of the factors causing the emission trends are presented in Tables 4 and 5, for NMHC and NO_x respectively. As indicated by Table 4, all major source categories of hydrocarbons were subjected to controls between 1974 and 1978. Total NMHC emissions changed very little, however, because of growth. Over the four years, population in the study area increased by 12%; the petroleum industry grew by 24%, automotive traffic increased by 30%, and chemical processing rose by 78%.

The petroleum and chemical industry growth factors for NO_x in Table 5 are less than the corresponding NMHC growth factors in Table 4. This is because the growth factors for NO_x include the effects of a conservation program with respect to fuel burning in those industries. The growth factors for NO_x are nevertheless substantial for all major source categories. These substantial growth rates, in the absence of NO_x controls (except for automobiles), led to significant increases in NO_x, especially in the chemical industry.

It should be noted that part of the reason for the lack of NMHC reductions from 1974 to 1978 is that many, if not most, of the stationary source controls were already in effect before 1974, and in many cases before 1973. The prime examples are: refinery storage (changing from 75% control in 1974 to 84% control in 1978), chemical storage (changing from 54% control in 1974 to 70% control in 1978), and petroleum/chemical loading (changing from 17% control in 1974 to 22% control in 1978). Only the chemical industry,

TABLE 4. CONTROL AND GROWTH FACTORS AFFECTING NMHC EMISSION TRENDS FROM 1974 TO 1978.

SOURCE CATEGORY	1974 Emissions (1000 tons/year)		Four-year Control Factor 1978 ÷ 1974		Growth Factor 1978 ÷ 1974		1978 Emissions (1000 tons/year)	Emission Changes, 1978 Minus 1974	
								Absolute (1000 tons/year)	Percent
Chemical Industry	138.5	x	0.37	x	1.78	=	91.3	-47.2	-34%
Petroleum Industry	92.0	x	0.89	x	1.24	=	101.0	+ 9.0	+10%
Motor Vehicles	107.7	x	0.80	x	1.30	=	111.6	+ 3.9	+ 4%
Other Sources	49.1	x	0.99	x	1.16	=	56.6	+ 7.5%	+15%
Whole Inventory	387.3	x	0.69	x	1.35	=	360.5	-26.8	- 7%

TABLE 5. CONTROL AND GROWTH FACTORS AFFECTING NO_x EMISSION TRENDS FROM 1974 TO 1978.

SOURCE CATEGORY	1974 Emissions (1000 tons/year)		Four-year Control Factor 1978 ÷ 1974		Growth* Factor 1978 ÷ 1974		1978 Emissions (1000 tons/year)	Emission Changes, 1978 Minus 1974 Absolute (1000 tons/year)	Emission Changes, 1978 Minus 1974 Percent
Chemical Industry	62.4	x	1.00	x	1.43	=	89.1	+26.7	+43%
Petroleum Industry	53.2	x	1.00	x	1.13	=	59.9	+ 6.7	+13%
Power Plants	44.8	x	1.00	x	1.15	=	51.5	+ 6.7	+15%
Motor Vehicles	89.2	x	0.83	x	1.30	=	95.8	+ 6.6	+ 7%
Other Sources	23.9	x	1.00	x	1.13	=	27.0	+ 3.1	+13%
Whole Inventory	273.5	x	0.94	x	1.26	=	323.3	+49.8	+18%

*Includes fuel conservation.

which instituted most of its process controls from 1974 (14% control) to 1978 (80% control), experienced significant NMHC reductions over the four year period.

SPATIAL DISTRIBUTION OF EMISSION TRENDS

Table 6 summarizes emission trends for the sub-areas of the study region: Brazoria County, Galveston County, and Harris County (further subdivided into the Ship Channel area, the Houston city area excluding the Ship Channel area, and the remainder of Harris County) The table presents year-by-year emission levels as well as the net change in emissions from 1974 to 1978 (the years covered by air quality data).

Table 6a shows that, with the exception of Brazoria County, most subareas of the region experienced little change in NMHC emissions from 1974 to 1978. Brazoria County underwent a significant decrease in NMHC because the chemical industry (which was controlled during the period) is the dominant source category there. The region-wide 7% decrease in NMHC was composed of a 34% decrease in Brazoria County, a 13% decrease in Galveston County, and a 1% increase in Harris County.

Table 6b reveals that all sub-areas of the region underwent increases in NO_x emissions from 1974 to 1978. The rise in NO_x was particularly large in the Ship Channel area (45%) because of growth in the chemical and petroleum industries there. The region-wide 18% rise in NO_x was composed of a 20% rise in Brazoria County, a 7% rise in Galveston County, and a 22% rise in Harris County.

EMISSION TRENDS FOR THE EKMA VALIDATION STUDY

Because of limitations imposed by the availability of ambient ozone data, the isppleth validation studies will be conducted for the years 1974 to 1978 at Mae Drive and 1975 to 1978 at Aldine. At each site, the initial year will serve as a base year, with isopleth predictions of ozone for subsequent years being compared to actual ozone concentrations. In order to determine the isopleth predictions for each year, net percent emission changes (with respect to the base year) are needed for the relevant source area.

TABLE 6. GEOGRAPHICAL DISTRIBUTION OF HISTORICAL PRECURSOR EMISSION TRENDS.

Table 6a. NMHC Emissions (1000 tons/year).

	1973	1974	1975	1976	1977	1978	Net Percent Change 1974 to 1978
HARRIS COUNTY (total)	275.2	263.1	230.3	228.8	270.0	264.6	+ 1%
Ship Channel	139.1	124.5	97.0	93.0	128.4	120.3	- 3%
Houston city	115.6	118.1	111.4	115.2	119.5	120.9	+ 2%
Remainder of Harris	20.5	20.5	21.9	20.6	22.1	23.4	+14%
BRAZORIA COUNTY	62.9	58.3	40.1	37.4	35.2	38.2	-34%
GALVESTON COUNTY	71.3	66.1	57.3	54.9	58.3	57.6	-13%
ENTIRE STUDY REGION	409.4	387.5	327.7	321.1	363.5	360.5	- 7%

Table 6b. NO_x Emissions (1000 tons/year).

	1973	1974	1975	1976	1977	1978	Net Percent Change 1974 to 1978
HARRIS COUNTY (total)	158.3	156.0	159.1	168.5	188.9	190.0	+22%
Ship Channel	41.5	39.7	41.4	42.7	58.8	57.7	+45%
Houston city	91.1	92.4	91.6	98.3	101.6	103.0	+11%
Remainder of Harris	25.7	23.9	26.1	27.5	28.5	29.3	+23%
BRAZORIA COUNTY	61.2	60.4	56.9	63.7	61.1	72.4	+20%
GALVESTON COUNTY	48.8	56.7	54.2	55.1	60.7	60.9	+ 7%
ENTIRE STUDY REGION	268.3	273.1	270.2	287.3	310.7	323.3	+18%

For the isopleth validation studies at both Mae Drive and Aldine, we have chosen Harris County as the appropriate source area. This choice is based on our findings in Chapter 2, that the highest ozone levels[*] at both Mae Drive and Aldine tend to occur under stagnation conditions, transport from the Ship Channel area, and transport from the Houston city area. Some readers might argue that we should select a larger source area (e.g. include all three counties) or a smaller source area (e.g. exclude the "remainder of Harris County" area). It should be noted, however, that such selections of source areas would produce nearly the same results in the validation study as does our choice of a source area.

The changes in NMHC and NO_x emissions for Harris County (with respect to 1974 and 1975 base years) are listed in Table 7 and illustrated in Figure 17. The table and figure also present error bounds for the emission estimates. The error bounds are based on crude error calculations and our subjective evaluation of uncertainties in the analysis. The error bounds are slightly non-symetric (larger errors in the direction of emission increases) because trends in the ambient precursor data suggest that we may have underestimated historical emission increases (see next section).

COMPARISON OF EMISSION TRENDS WITH AMBIENT PRECURSOR DATA

Ambient data for NMHC and NO_x are available for the years 1974-1978 and 1975-1978, respectively.[**] Although weather-induced air quality fluctuations make interpretation of ambient trends very tenuous over the period of a few years, it its worthwhile to check the ambient precursor data for consistency with our emission trend estimates.

Figures 18 and 19 illustrate ambient trends for NMHC and NO_x in terms of three air quality indices: 6-9 AM concentrations averaged over the smog

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[*] Note that the air quality indices used in the validation studies -- second highest one hour ozone, and 95th percentile of daily maximum ozone during the smog-season -- emphasize the highest ozone days.

[**] The exact start dates for the ambient precursor data are as follows: 10/10/73 for NMHC at Mae Drive, 4/25/74 for NMHC at Aldine, 3/10/75 for NO_x at Mae Drive, and 2/21/75 for NO_x at Aldine. We have used yearly means for 1974 NMHC at Aldine and 1975 NO_x at both sites despite the fact that the first parts of these yearly data sets are missing.

TABLE 7. EMISSION TRENDS TO BE USED IN THE ISOPLETH VALIDATION STUDIES.

Table 7a. Harris County Emission Trends Using 1974 as a Base Year (for Use with Mae Drive).

	NET PERCENT CHANGE FROM BASE YEAR			
YEAR	NMHC		NO_x	
1974	0%		0%	
1975	-12%	+ 8% - 6%	+ 2%	+ 5% - 3%
1976	-13%	+ 10% - 8%	+ 8%	+ 9% - 6%
1977	+ 3%	+ 14% - 12%	+21%	+ 14% - 10%
1978	+ 1%	+ 16% - 14%	+22%	+ 20% - 14%

Table 7b. Harris County Emission Trends Using 1975 as a Base Year (for Use with Aldine).

	NET PERCENT CHANGE FROM BASE YEAR			
YEAR	NMHC		NO_x	
1975	0%		0%	
1976	- 1%	+ 8% - 8%	+ 6%	+ 8% - 6%
1977	+17%	+ 11% - 11%	+19%	+ 12% - 10%
1978	+15%	+ 14% - 14%	+19%	+ 17% - 13%

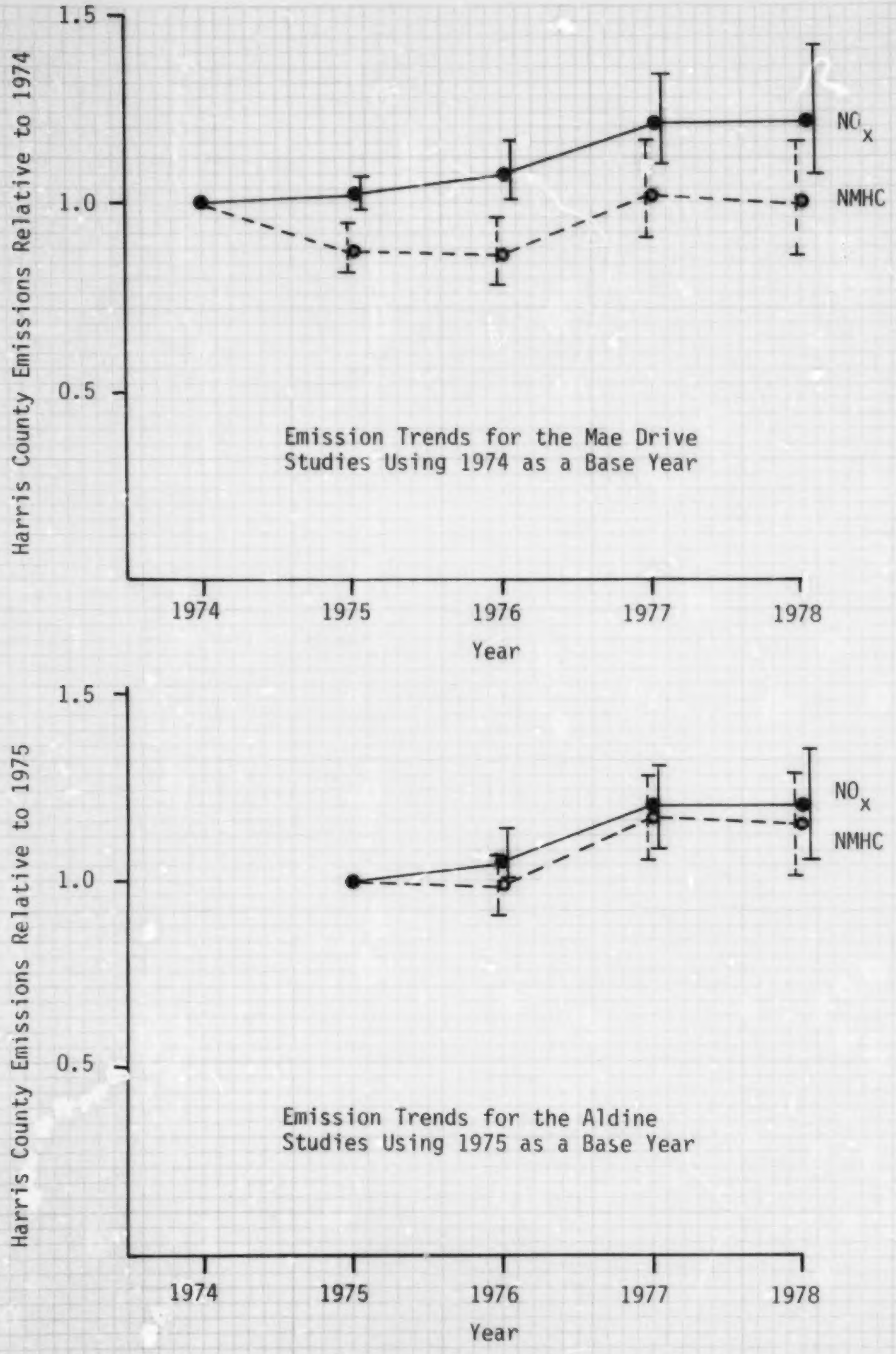

Figure 17. Emission trends for the isopleth validation studies.

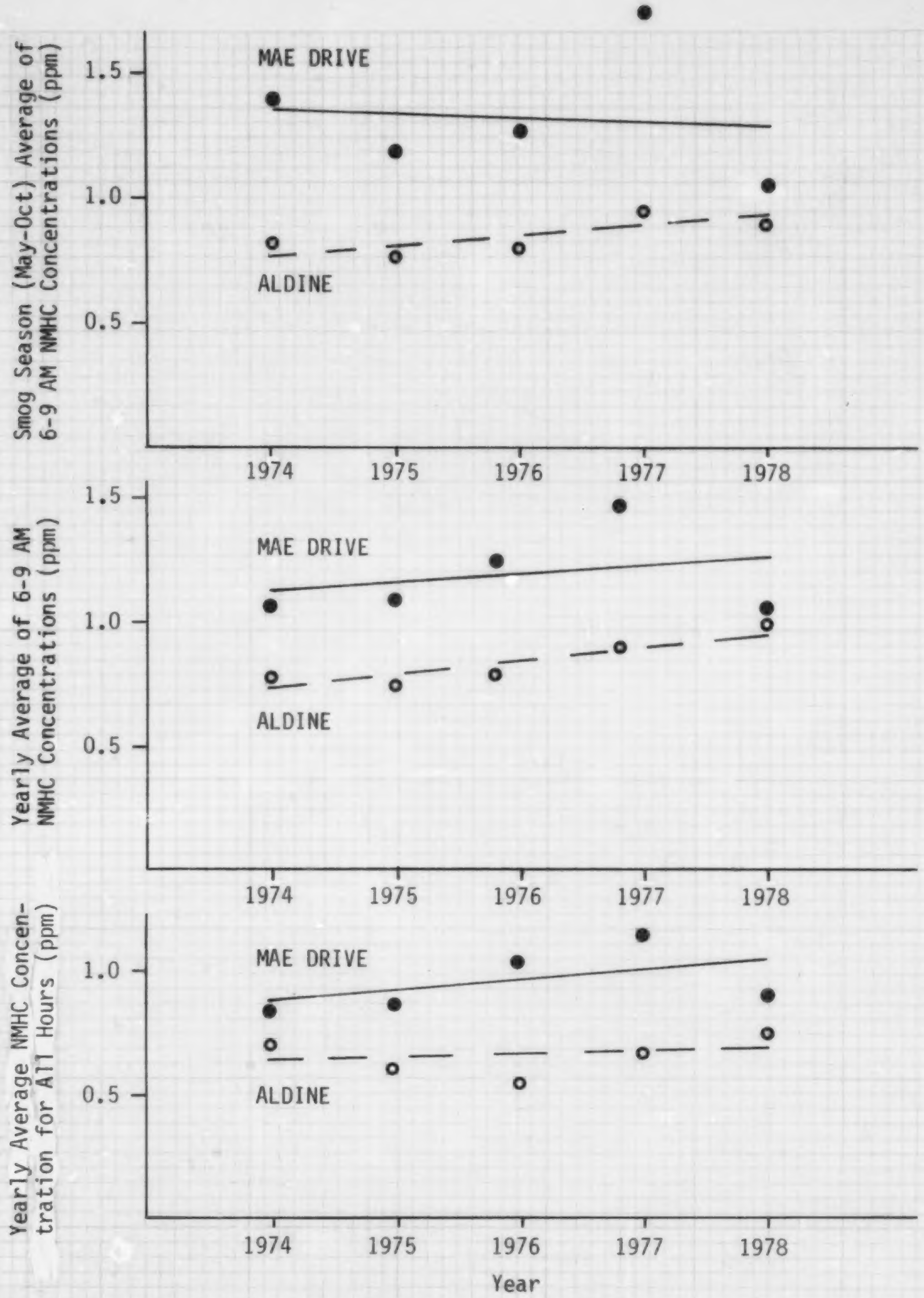

Figure 18. Trends in ambient NMHC for various air quality indices at Mae Drive and Aldine.

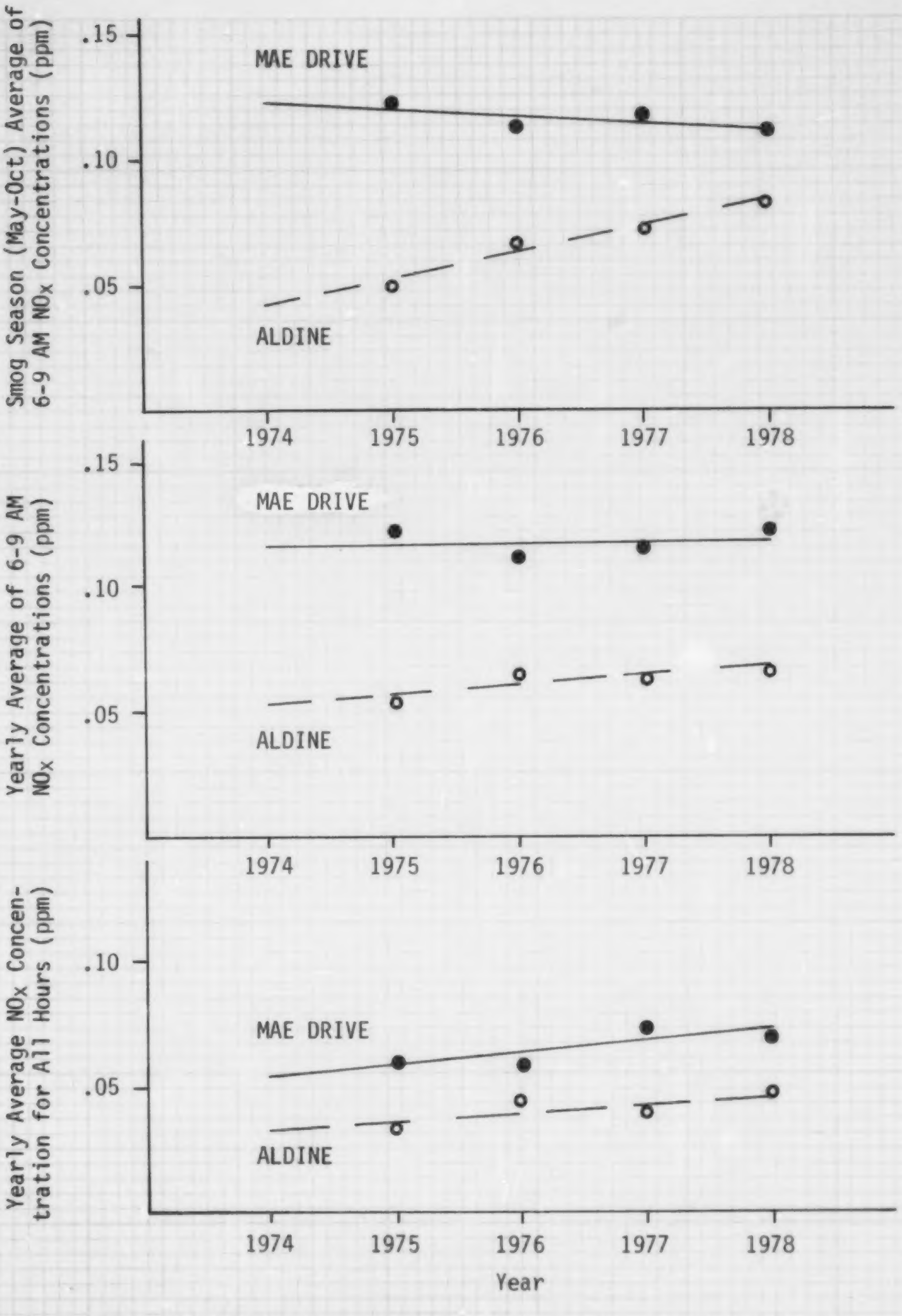

Figure 19. Trends in ambient NO_x for various air quality indices at Mae Drive and Aldine.

season, 6-9 AM concentrations averaged over the years, and annual mean concentrations (all hours). The figures also include regression lines fit to the data.

The net percent changes in ambient precursor concentrations from 1974 to 1978, as determined from the regression lines, are summarized in Table 8. Table 8 also lists net NMHC and NO_x emission changes for Harris County from 1974 to 1978. It is apparent that the ambient data present a somewhat more pessimistic view of precursor trends than do our emission trend estimates. For example, estimated NMHC emissions in Harris County increased by 1% from 1974 to 1978 while ambient NMHC concentrations apparently increased on the order of 7 to 23%; estimated NO_x emissions increased by 22% from 1974 to 1978 while ambient NO_x concentrations apparently increased on the order of 16 to 48%. We are unsure as to the cause of this discrepancy. As discussed in this chapter and Appendix B, there is considerable uncertainty in the emission trend estimates; our emission trend estimates may be overly optimistic. On the other hand, there is also considerable potential for error in the ambient trend data due to yearly meteorological fluctuations and to possible undocumented changes in monitoring practices. The comparison of the emission trends with the ambient trends serves as a further justification for the rather large error bounds we have placed on our emission trend estimates.

TABLE 8. NET 1974-1978 CHANGES IN AMBIENT PRECURSOR CONCENTRATIONS.*

Table 8a. Percent Changes for NMHC.

Note: Estimated Harris County Emission Change = +1%.

SITE	NET PERCENT CHANGE, 1974-1978		
	Smog-Season 6-9 AM Concentration	Yearly 6-9 AM Concentration	Yearly Average Concentration
Mae Drive	- 5%	+14%	+20%
Aldine	+19%	+32%	+12%
Average	+ 7%	+23%	+16%

Table 8b. Percent Changes for NO_x.

Note: Estimated Harris County Emission Change = +22%.

SITE	NET PERCENT CHANGE, 1974-1978		
	Smog-Season 6-9 AM Concentration	Yearly 6-9 AM Concentration	Yearly Average Concentration
Mae Drive	- 8%	+ 2%	+31%
Aldine	+103%	+29%	+41%
Average	+48%	+16%	+36%

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*Determined by regression lines fit to yearly concentrations.

CHAPTER 4

HISTORICAL OZONE TRENDS

Information on historical ozone trends in Houston is one of the inputs needed to check the EKMA isopleth method. This chapter provides this information in terms of aggregate year-to-year changes in smog-season data for ozone. In an attempt to gain insights into the causes of ozone trends, this chapter also analyzes historical ozone trends disaggregated by wind direction.

OZONE TREND DATA FOR USE IN THE VALIDATION STUDIES

The validation studies will cover the years 1974-1978 at Mae Drive and 1975-1978 at Aldine; these are the only years for which complete smog-season data are available at the two sites. For each location, the initial year will serve as a base-year, with the EKMA isopleth model being tested for all subsequent years.

Selection of Air Quality Indices

Because the EKMA isopleth model applies to days of maximal oxidant, the validation studies require air quality indices that are representative of high ozone days. We would also like to select air quality indices that exhibit relatively low year-to-year variance, because the statistical variation in ambient ozone levels constitutes one of the critical error bounds in our analysis.

Table 9, based on 11 years of data at 11 Los Angeles locations[*], summarizes the overall magnitude and year-to-year deviation of various ozone air quality indices. It is obvious that a trade-off exists between indices that are representative of high ozone days and those that have a low yearly standard deviation. The indices "yearly maximum concentration" and "yearly second maximum concentration" reflect worst-case ozone days but display a yearly standard deviation of ± 17%. The indices "annual mean of all hours"

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[*] Insufficient data are available for a meaningful study of the variance in alternative ozone air quality indices for Houston.

TABLE 9. AVERAGE YEARLY VALUES AND YEAR-TO-YEAR DEVIATIONS FOR OZONE AIR QUALITY INDICES.

OZONE AIR QUALITY INDEX	MEAN VALUE OF INDEX FOR 11 LOCATIONS DURING 1965-1975 (pphm)	DE-TRENDED YEAR-TO-YEAR DEVIATION AVERAGED OVER 11 LOCATIONS (as % of mean value for the index)
1. 99th Percentile of All Hours	17.4	± 11.5%
2. 95th Percentile of All Hours	10.9	± 12.1%
3. Annual Mean of All Hours	3.0	± 11.1%
4. Yearly Maximum 1-Hour	33.3	± 17.0%
5. Second Highest 1-Hour	30.8	± 16.5%
6. 99th Percentile of Daily Maximum 1-Hour	26.9	± 13.0%
7. 95th Percentile of Daily Maximum 1-Hour	20.3	± 11.5%
8. 90th Percentile of Daily Maximum 1-Hour	17.0	± 11.9
9. 3rd Quarter Mean of Daily Maximum 1-Hour	13.2	± 14.2%
10. Yearly Mean of Daily Maximum 1-Hour	8.6	± 10.6%

and "yearly mean of daily maximum one-hour" have a variance of only ± 11% but do not adequately represent high ozone conditions.

For the Houston validation study, we will use two ozone air quality indices: the yearly second maximum concentration and the 95th percentile of daily maximum 1-hour concentrations (during the smog season). The yearly second maximum concentration must be studied because it often serves as the basis for implementation planning. The 95th percentile of daily maximum 1-hour concentrations during the smog season is a good index for the validation studies because it reflects high ozone days but exhibits relatively low yearly variance (see Table 9).

Illustration of Trend Data

Historical ozone trends -- for the yearly second maximum 1-hour, the 95th percentile of daily maximum 1-hour during the smog season, and the average of daily maximum 1-hour during the smog season -- are listed in Table 10 and presented in Figures 20 and 21. No consistent historical trends seem evident in any of the data except for the yearly second maximum 1-hour concentrations at Aldine which display a significant decrease from 1975 to 1978. As noted previously in Chapter 2, ozone concentrations are higher at Aldine than at Mae Drive.

Calculation of Error Bounds

When comparing actual ozone trends to ozone trends predicted by the isopleth model, we need to place error bounds on the actual trends to represent the variance due to meteorological fluctuations. Because we will take the initial (base year) conditions as given and will examine ozone changes relative to those conditions, the error of interest is the error in the difference between air quality for the base year and air quality for subsequent years. To obtain the error in this difference, the yearly standard deviations must be multiplied by $\sqrt{2}$.[*]

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[*] The standard error in the sum or difference of two variables, each with the same standard error (σ), is $\sqrt{2}\,\sigma$.

TABLE 10. HISTORICAL OZONE TREND DATA (PPM) FOR MAE DRIVE AND ALDINE.

YEAR	Yearly Second-Highest 1-Hour Maximum Concentration		95th Percentile of Daily Maximum 1-Hour Concentrations During Smog-Season		Average of Daily Maximum 1-Hour Concentrations During the Smog-Season	
	Mae Drive	Aldine	Mae Drive	Aldine	Mae Drive	Aldine
1974	.205	----	.137	----	.069	----
1975	.223	.300	.172	.156	.071	.079
1976	.267	.255	.165	.190	.072	.099
1977	.220	.261	.169	.172	.074	.081
1978	.200	.200	.155	.173	.070	.090

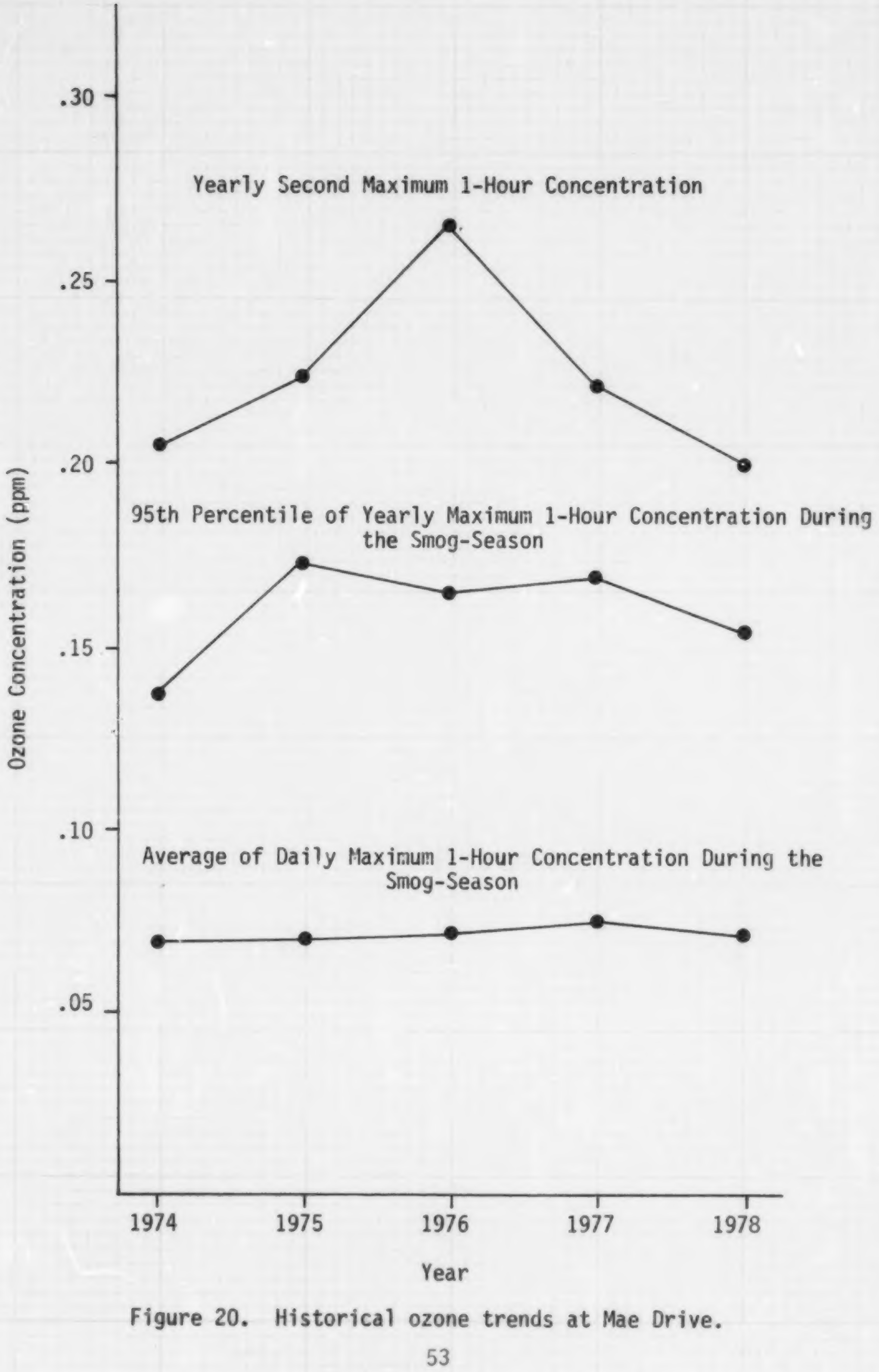

Figure 20. Historical ozone trends at Mae Drive.

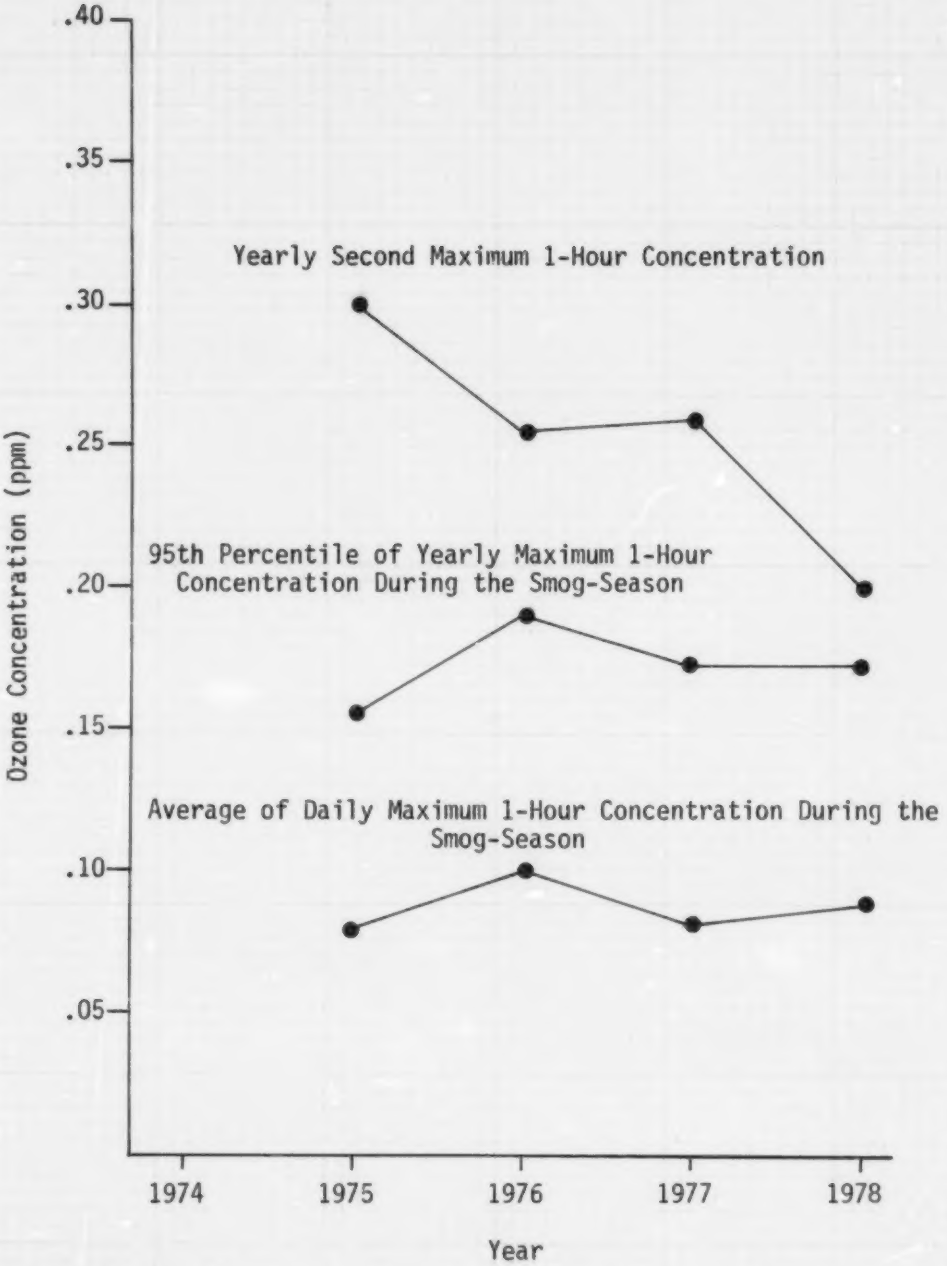

Figure 21. Historical ozone trends at Aldine.

Based on the Los Angeles results in Table 9, we assume that the yearly second maximum 1-hour concentration in Houston has a standard deviation of ± 17%, and that the 95th percentile of daily maximum concentrations during the smog season has a standard deviation of ± 12%. From the line of reasoning presented in the previous paragraph, the error bounds that we will use in our validation study are $\sqrt{2}$ times these, or ± 24% for the second maximum 1-hour concentration and ± 17% for the 95th percentile of daily maximum 1-hour concentrations during the smog season.

Meteorological Adjustment of Ozone Data

Originally, we intended to conduct the validation studies using ozone trends that had been normalized for meteorology. Meteorological adjustment should eliminate weather biases in the trends and should also decrease the statistical error bounds on the actual ozone trends, resulting in a more finely-tuned validation study.

The meteorological adjustment was to be performed according to methods proposed by Zeldin and Meisel (1978). In another phase of the present study (Zeldin 1979), further development and testing of these methods were conducted with Los Angeles ozone data. The testing based on Los Angeles data encountered fundamental difficulties with meteorological normalization, the main problem areas being as follows: (1) different results were obtained using different techniques for meteorological adjustment, (2) the assumptions used to compute confidence intervals (error bounds) were invalid, and (3) relatively little of the year-to-year variance in ozone was explained. Because of these problems, Zeldin (1979) concluded that further research into meteorological normalization procedures was necessary before such procedures could be used in practice. Thus, we were not able to perform meteorological adjustment of the ozone data in our Houston validation study.

OZONE TRENDS BY WIND DIRECTION

Figures 22 and 23 illustrate ozone trends (smog season averages of daily 1-hour maxima) stratified by wind direction[*] for Mae Drive and Aldine,

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[*] Following the procedure established in Chapter 2, daily wind direction is determined by a vector average from 9:00 AM to 3:00 PM CDT.

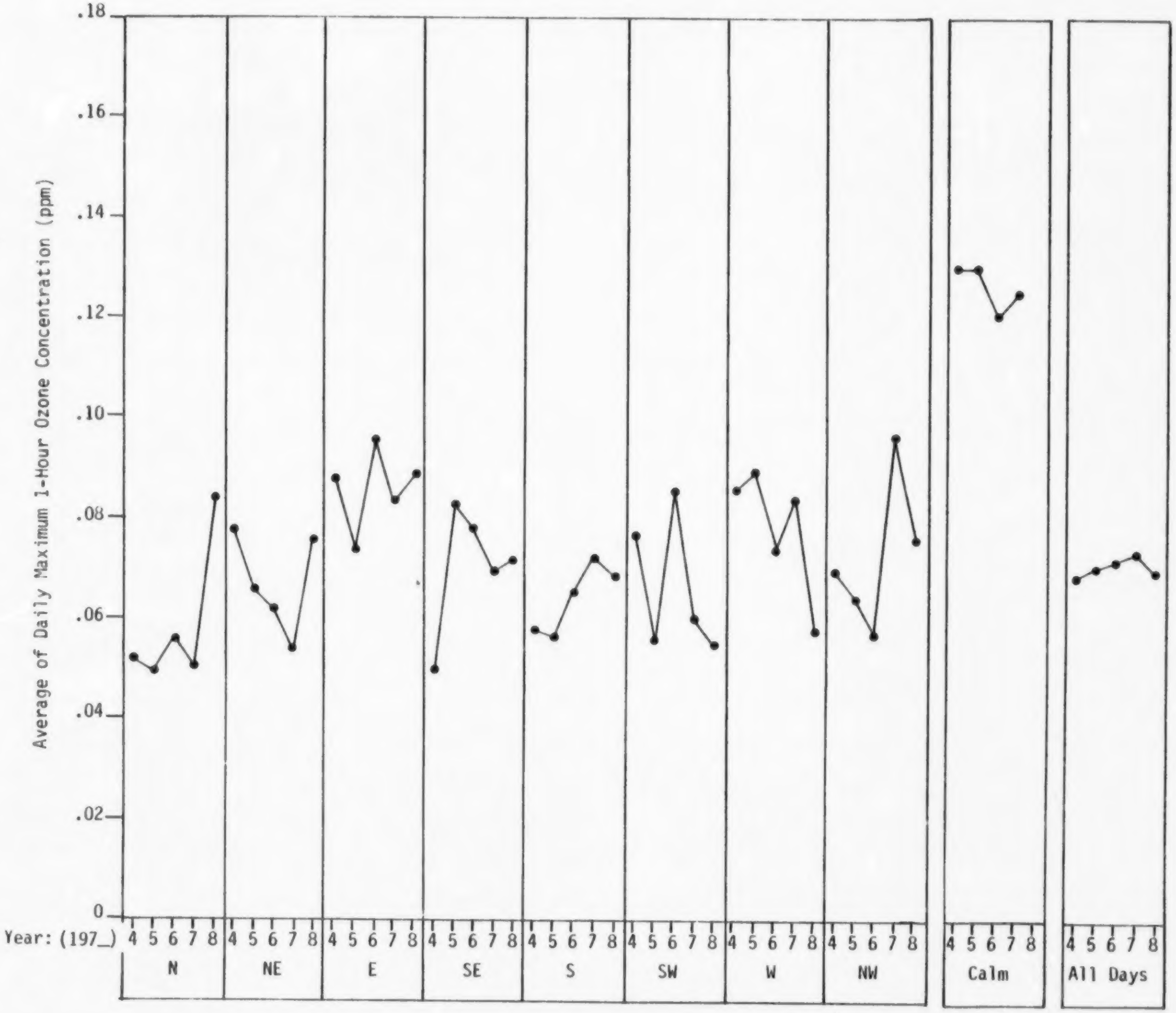

Figure 22. Trends in smog-season averages of daily maximum ozone concentrations at Mae Drive sorted by wind direction.

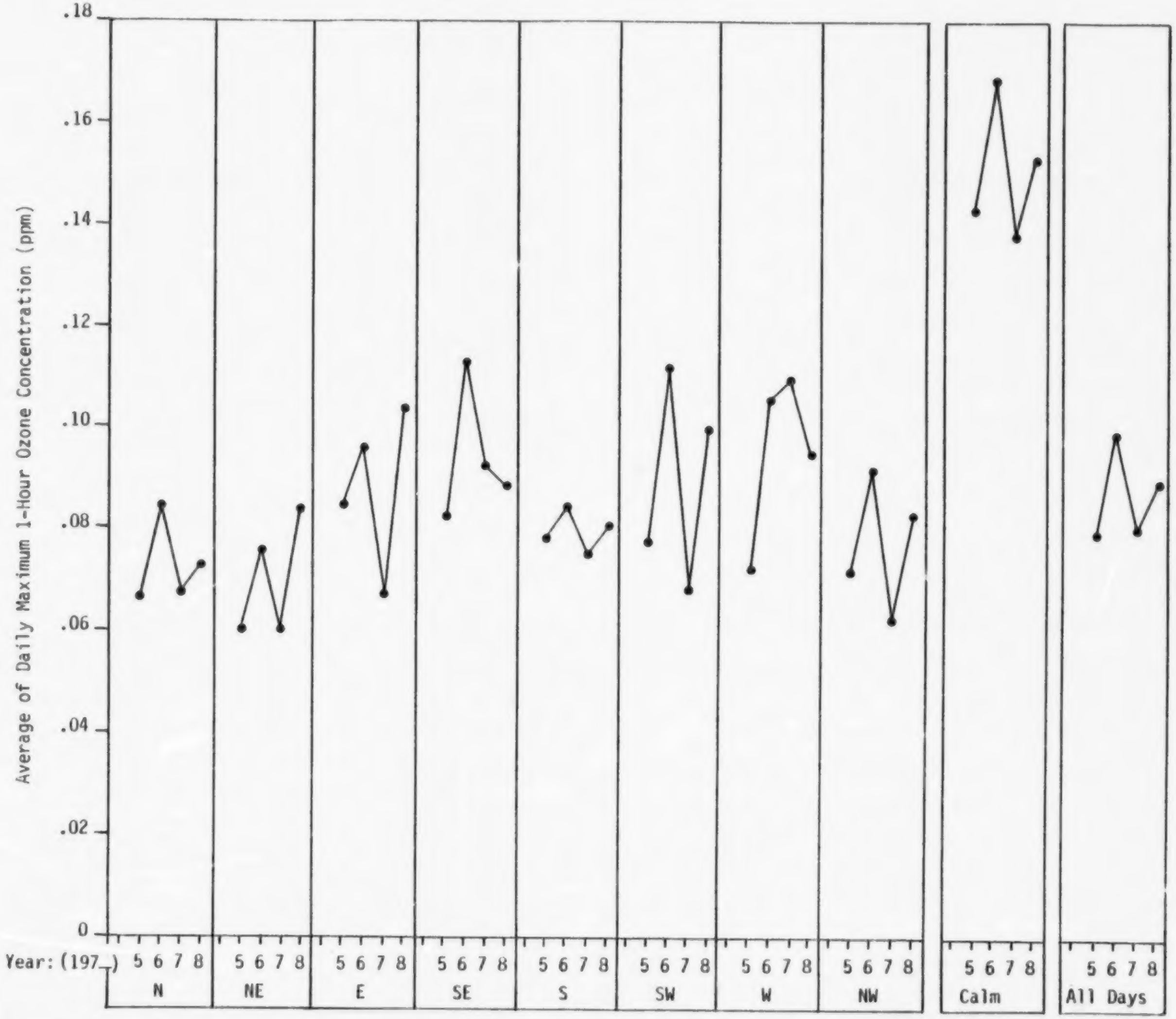

Figure 23. Trends in smog-season averages of daily maximum ozone concentrations at Aldine sorted by wind direction.

respectively. Scrutiny of these figures indicates that the results are dominated by random fluctuations rather than consistent patterns. The randomness is suggested by three features: (1) trends for a given wind direction at a given site display up and down fluctuations from year to year rather than monotonic increases or decreases; (2) trends for adjacent wind directions at a given site do not resemble one another; and (3) trends for given source areas (e.g. the Houston city area west of Mae Drive and southwest of Aldine) are dissimilar at Mae Drive and Aldine. The predominance of the stochastic fluctuations is partly due to paucity of data; there are only about 10-20 daily data points for each wind direction each year.

CHAPTER 5

VALIDATION OF THE EKMA ISOPLETH METHOD

This chapter describes the Houston validation studies of the EKMA isopleth method. Historical emission trends and the EKMA isopleth model are used to predict historical ozone trends in Houston; these predicted ozone trends are then compared to actual ozone trends. The validation studies are conducted for two monitoring sites, Mae Drive and Aldine, as well as for two ozone air quality indices, the 95th percentile of daily maximum 1-hour concentrations during the smog season (abbreviated as "95th percentile of daily maxima") and the yearly second maximum 1-hour concentration (abbreviated as "yearly second maximum").

SELECTION OF NMHC/NO_x RATIOS AND EKMA SIMULATION CONDITIONS

Before we proceed with model validation, two more preliminary issues must be resolved. One is the choice of NMHC/NO_x ratios to be used with the isopleth method; the other is selection of EKMA simulation conditions.

NMHC/NO_x Ratios

Table 11 lists 10th, 50th, and 90th percentiles of ambient 6-9 AM NMHC/NO_x ratios at Mae Drive and Aldine. It should be noted that these ratios have been divided by a factor of 0.7 to make the NMHC data (based on methane calibrated instruments) approximately equivalent to NMHC data based on propane calibrated instruments [that is -- to make the NMHC measurement techniques equivalent to the techniques used in the chamber studies that serve as a foundation for EKMA (Dimitriades 1970, 1972, 1977b)]. The 0.7 factor is a crude first-order correction factor; the actual differences between methane and propane calibration depend on the specific hydrocarbon mix as well as the specific monitoring device.

Because EKMA guidelines (EPA 1978) indicate that NMHC/NO_x ratios on days of high ozone should be considered, Table 11 lists ratios for days when maximum one-hour ozone exceeds 0.15 ppm as well as for all smog season days. The percentiles for higher ozone days are uncertain because of sparse data (see footnote in Table 11); taking into account this uncertainty, no significant difference can be discerned between the percentiles for high ozone days and those for all smog season days.

For the isopleth validation studies, we have decided to use percentile NMHC/NO_x ratios based on data for the entire smog season and averaged over Mae Drive and Aldine. From Table 11, the appropriate ratios are a 10th percentile of 8.5:1, a median of 17:1, and a 90th percentile of 47:1.

TABLE 11. AMBIENT 6-9 AM NMHC/NO RATIOS DURING THE SMOG SEASON IN HOUSTON.*

	RATIOS FOR THE ENTIRE SMOG SEASON		RATIOS ON DAYS WHEN MAXIMUM 1-HOUR OZONE EXCEEDED 0.15 PPM	
RATIO PERCENTILE	Mae Drive	Aldine	Mae Drive**	Aldine**
10th Percentile	7	10	4	11
Median	14	20	16	16
90th Percentile	46	48	39	30

*Based on data for May-October, 1975-1977. Note that the NMHC data used in these ratios has been divided by a factor of 0.7 to make the NMHC data (based on methane calibrated instruments) approximately equivalent to data based on propane calibrated instruments.

**Note that there are very few days (8 days at Mae Drive and 13 days at Aldine) when maximum 1-hour ozone exceeded 0.15 ppm and 6-9 AM data were available for both NMHC and NO_x. Thus, the percentiles for high ozone days involve considerable uncertainty.

EKMA Simulation Conditions

For use in the validation studies at both Mae Drive and Aldine, we have selected the Standard EKMA Isopleths for basinwide maximum ozone (EPA 1977, 1978). These isopleths pertain to the maximum ozone produced during 10-hour irradiations under the following conditions: diurnal sunlight intensity corresponding to 8 AM - 6 PM LDT for the summer solstice at 34° N latitude (Houston is 300 miles south of this latitude); a dilution rate of 3% per hour for the first 7 hours and zero dilution thereafter; no emissions after 8 AM; and a hydrocarbon mix of 25% propylene and 75% n-butane with aldehydes of 5% the initial NMHC.

As discussed in Chapter 2, on days of highest ozone, the typical irradiation time up to peak ozone is 7 hours at both Mae Drive and Aldine. These facts suggest that an alternative isopleth model -- e.g., isopelths for the ozone concentration exactly at 7 hours irradiation -- might be considered. We have conducted a sensitivity study to determine how our results would change if this alternative isopleth model were used. Figures 24 to 26 present the results of the sensitivity study at Mae Drive for NMHC/NO_x ratios of 8.5:1, 17:1, and 47:1, respectively. Figures 24 and 25 show that the 7-hour isopleths yield nearly identical results as the basinwide isopleths for NMHC/NO_x ratios of 8.5:1 and 17:1. Figure 26 shows that the predictions based on the 7-hour isopleths differ somewhat from the predictions based on basinwide isopleths for an NMHC/NO_x ratio of 47:1. We are unsure how much of the difference in Figure 26 is due to the isopleth model and how much is due to the extreme difficulty of applying the graphical EKMA prediction technique accurately at very high NMHC/NO_x ratios (see next section for a description of the graphical EKMA prediction technique). Because the isopleth validation study basically focuses on the median NMHC/NO_x ratio of 17:1 (where our results are very insensitive to the choice of a simulation time), the choice of a specific EKMA simulation time does not appear to be a critical factor in the validation study.

RESULTS OF THE VALIDATION STUDIES

In the validation tests, predicted ozone trends are compared with actual ozone trends. The predicted ozone trends are determined from historical emission changes using the standard EKMA procedure (EPA 1977, 1978). Figure 27 illustrates this procedure for the case of second highest hourly ozone at Mae Drive and an NMHC/NO_x ratio of 17:1. The base year point (1974) is determined by the intersection of the 17:1 ratio line with the ozone value for the base year (second highest hour = 0.205 ppm). The location of points for subsequent years (1975-1978) are found by factoring the NMHC and NO_x coordinates of the base year point according to the NMHC

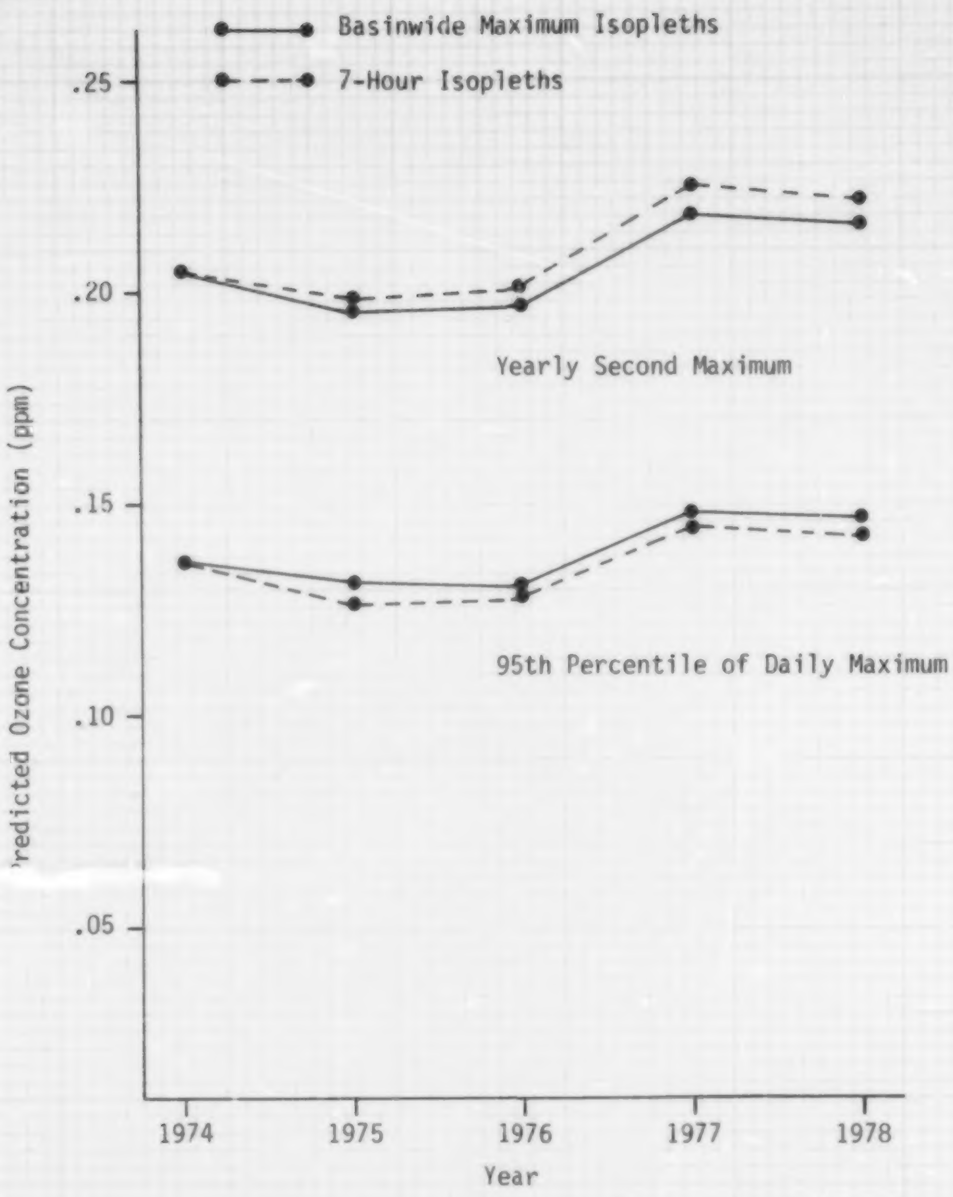

Figure 24. Comparison of predicted ozone using basinwide maximum isopleths and 7-hour isopleths for an NMHC/NO_x ratio of 8.5:1.

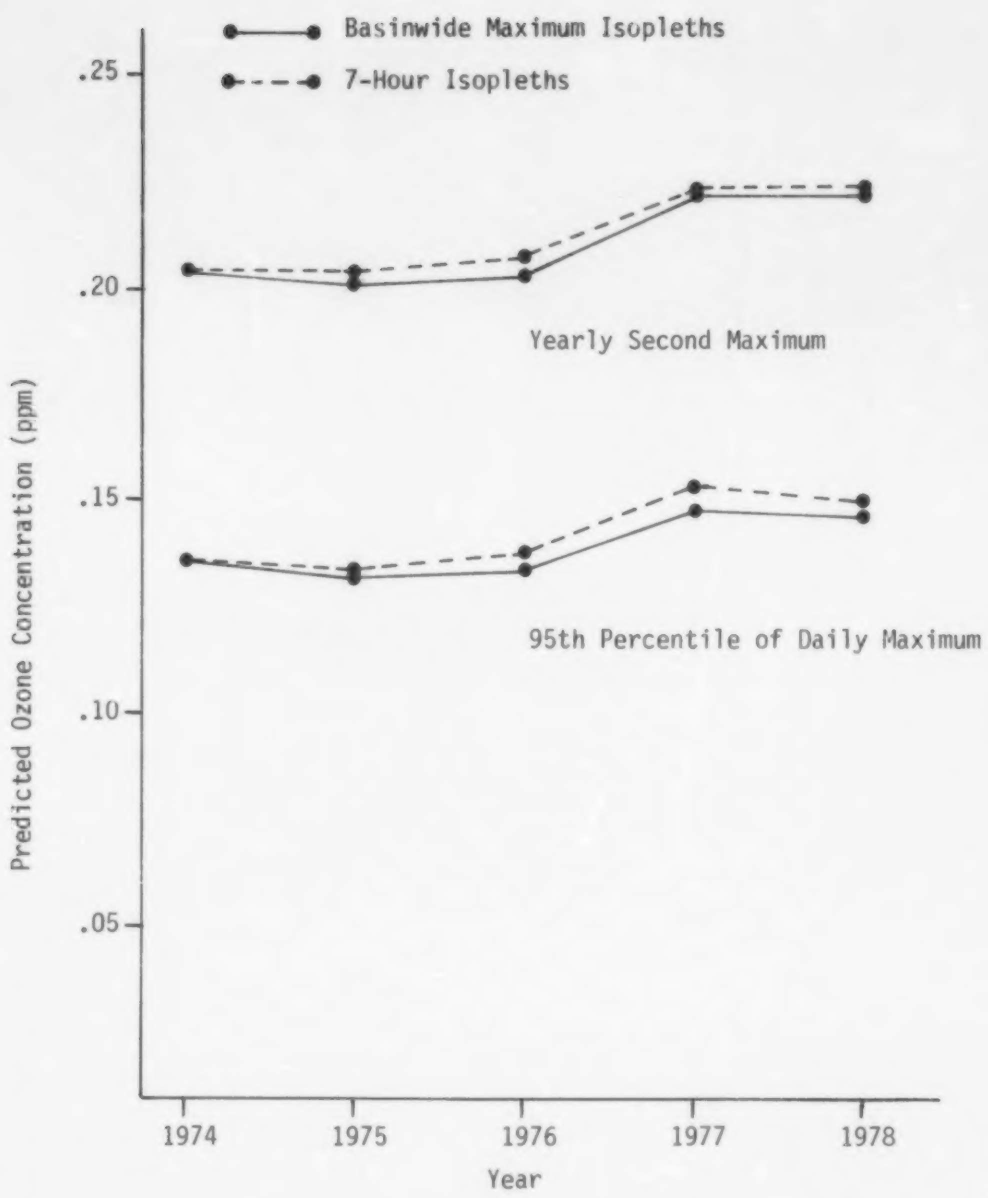

Figure 25. Comparison of predicted ozone using basinwide maximum isopleths and 7-hour isopleths for an NMHC/NO_x ratio of 17:1.

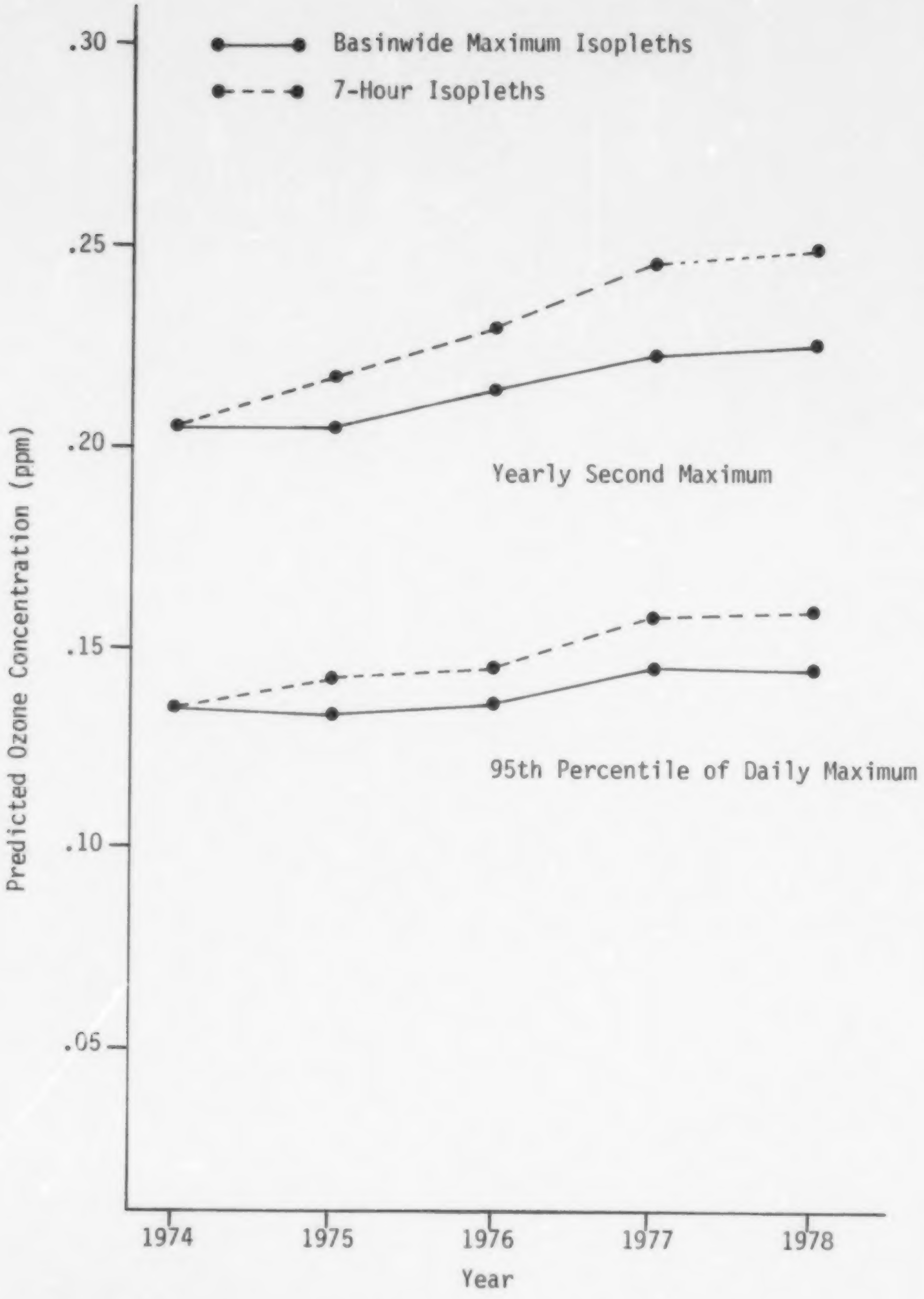

Figure 26. Comparison of predicted ozone using basinwide maximum isopleths and 7-hour isopleths for an NMHC/NO_x ratio of 47:1.

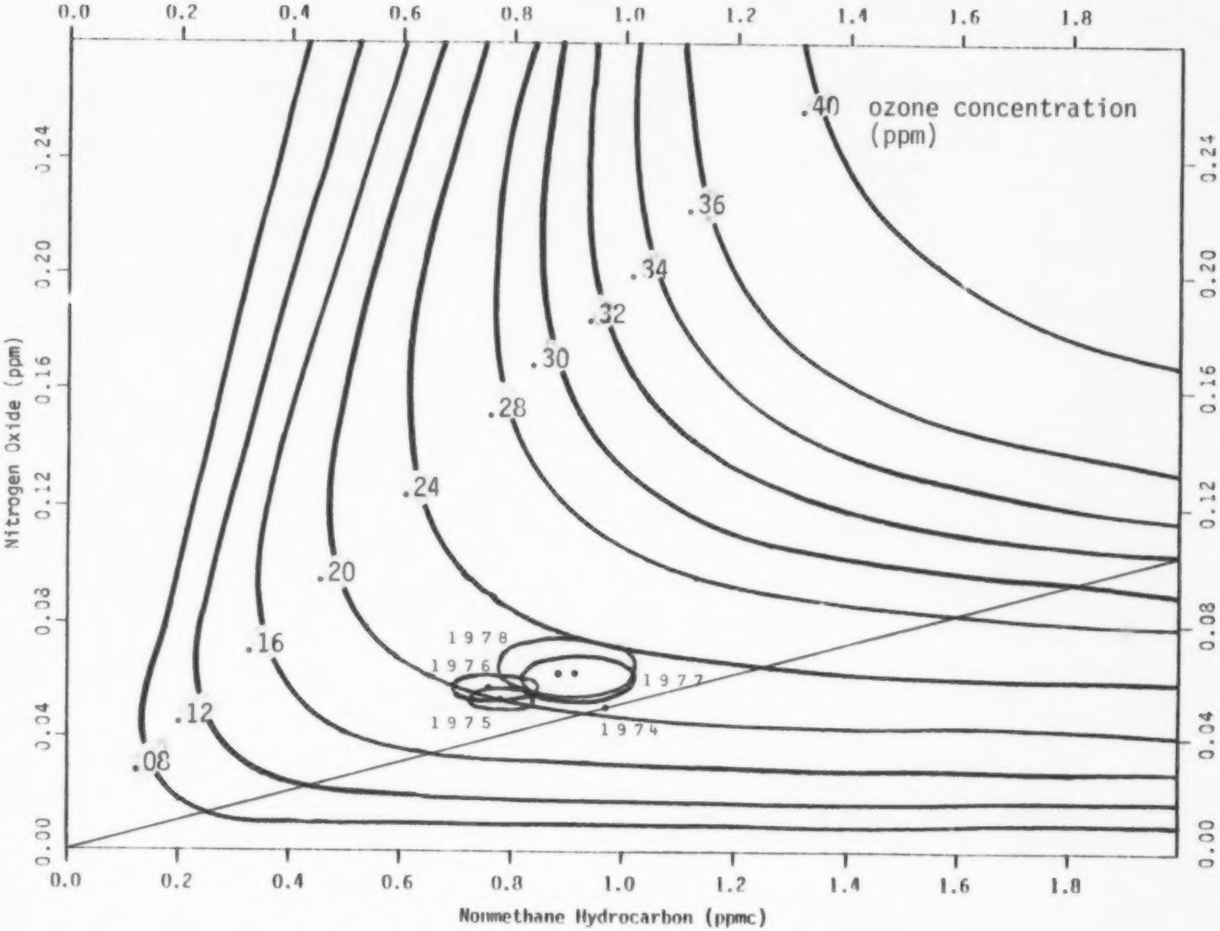

Figure 27. Illustration of the use of EKMA to predict historical ozone trends.

and NO_x emission changes relative to the base year. The isopleths then yield predicted ozone values for subsequent years.

Two types of error bounds are attached to predicted ozone concentrations. The first type, reflecting uncertainty in emission trend estimates, is determined from error-ellipses in the isopleth diagrams (see Figure 27). The size of these ellipses is based on the errors in emission trends as listed in Table 7 (Chapter 3). The second type of error bound on predicted ozone, reflecting uncertainty in the $NMHC/NO_x$ ratio, is determined by the range of predictions for the various ratios (8.5:1, 17:1, and 47:1). As discussed in Chapter 4, actual ozone trends also include error bounds representing the fluctuations in yearly air quality produced by meteorological variance.

Results for Mae Drive

Figures 28 and 29 summarize the validation studies for Mae Drive. Figure 28 pertains to the 95th percentile of daily maximum ozone, while Figure 29 pertains to the yearly second maximum ozone. Both figures are for an $NMHC/NO_x$ ratio of 17:1, with the error bounds on predicted ozone trends representing both the errors in emission trends and the range in the $NMHC/NO_x$ ratio.[*]

For both air quality indices, predicted ozone displays little change from 1974 to 1976, a slight increase from 1976 to 1977, and little change from 1977 to 1978. Actual ozone increases substantially in 1975 or 1976 and then shows a decline through 1978. The result is that predicted and actual ozone levels diverge somewhat in 1975-1976 but agree fairly well in 1977-1978. Given the rather large error bounds, we cannot be sure if the disagreement in 1975-1976 reflects a flaw in the EKMA method or if it is caused by potential errors in our analysis. In fact, the emission changes in Houston from 1974 to 1978 are not large enough relative to the potential

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[*] Our results show that the dominant part of the error in the predicted ozone trends arises from errors in the emission trends, with a relatively minor contribution from the variance in the $NMHC/NO_x$ ratio.

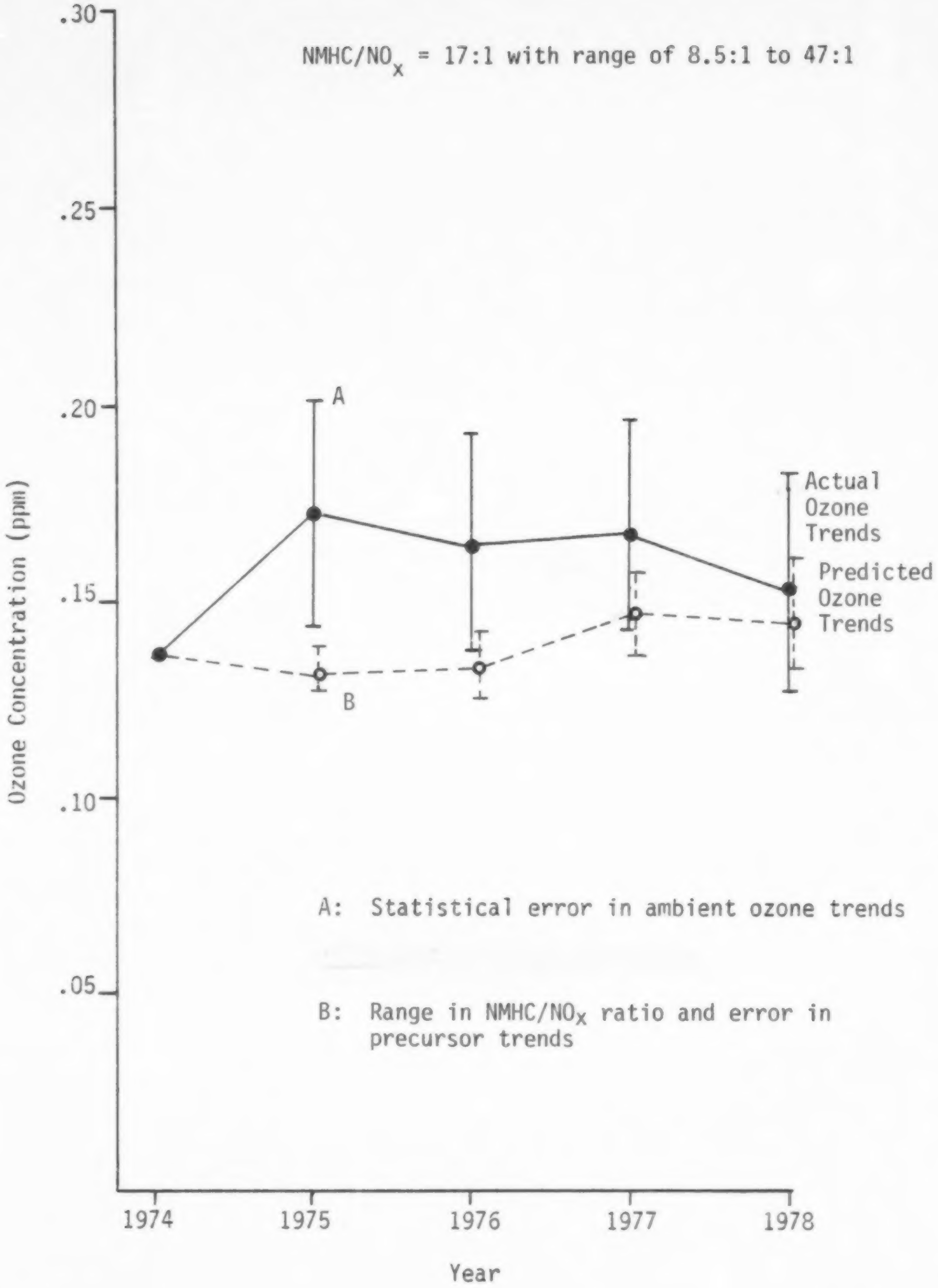

Figure 28. Summary of ozone trends for the 95th percentile of daily maxima at Mae Drive, predicted versus actual.

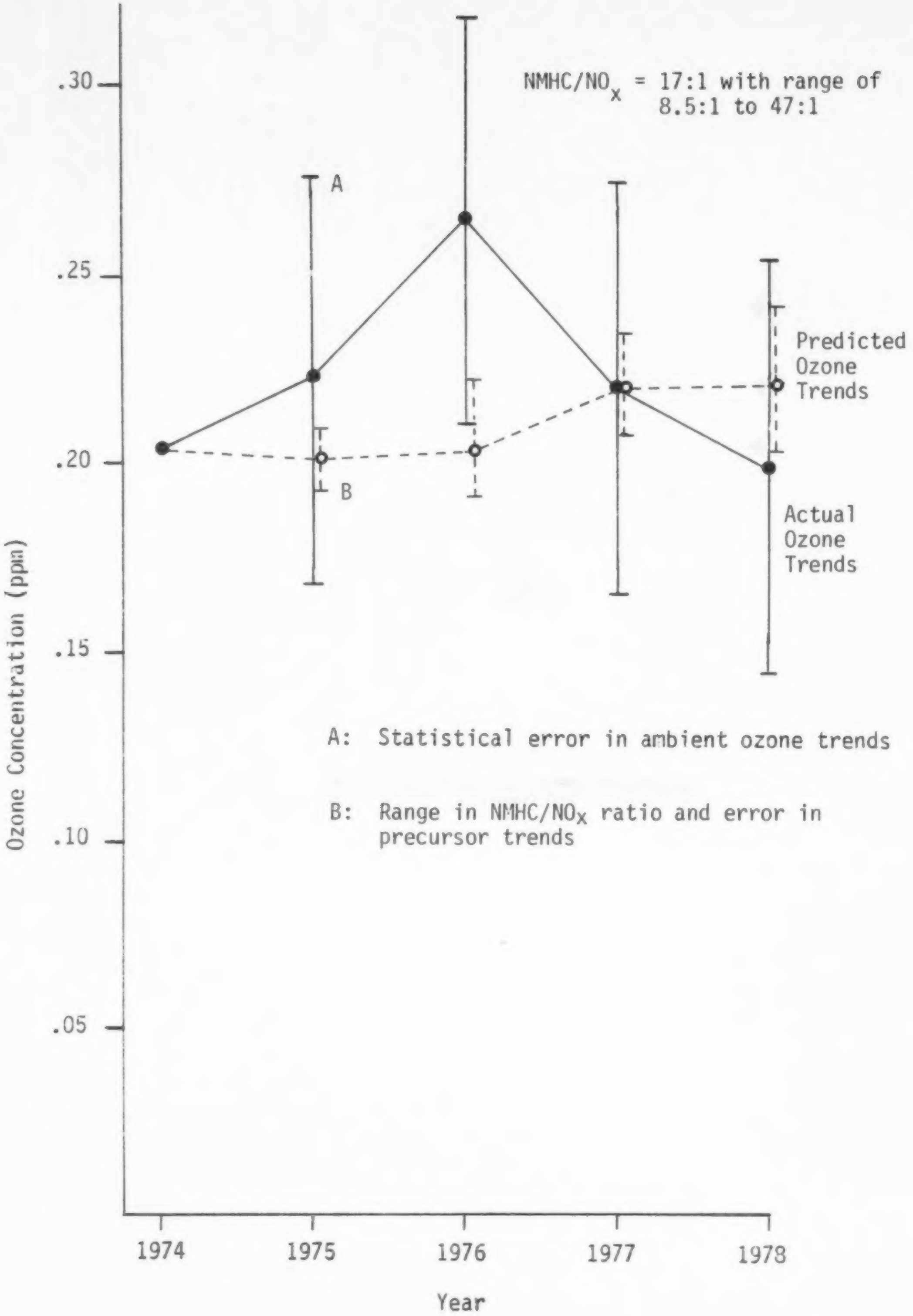

Figure 29. Summary of ozone trends for the yearly second maximum at Mae Drive, predicted versus actual.

errors in the analysis to provide an adequate test of the EKMA model.

Appendix C contains graphs comparing actual ozone trends at Mae Drive to predicted trends using NMHC/NO_x ratios of 8.5:1, 17:1, and 47:1. The predicted ozone trends are nearly identical for all three ratios. There are two reasons why the predicted trends are nearly the same for all three NMHC/NO_x ratios: (1) the historical emission changes are rather small, and (2) the emission changes over most of the period (from 1975 to 1978) involve simultaneous increases in both NMHC and NO_x; the EKMA model is insensitive to the initial NMHC/NO_x ratio in cases where NMHC and NO_x emissions undergo like changes.

Results for Aldine

As indicated by Figure 30, the predicted and actual trends for the 95th percentile of daily maxima at Aldine agree rather well. As shown in Figure 31, however, a very significant discrepancy exists for the yearly second maximum at Aldine. The predicted yearly second maxima show slight increases from 1975 through 1978, but the actual second maxima display substantial decreases. Potential explanations for this disagreement will be discussed in the next section.

Appendix D presents results for Aldine using NMHC/NO_x ratios of 8.5:1, 17:1, and 47:1 to derive predicted trends. As in the case of Mae Drive, the predicted trends are nearly identical for all three ratios.

DISCUSSION OF RESULTS

For both air quality indices at Mae Drive and for the 95th percentile of daily maxima at Aldine, there is a tendency for the isopleth model to underpredict ozone levels in 1975 and 1976 but to yield fairly good predictions in 1977 and 1978. This pattern might be explained by the two major sources of error in our analysis: statistical (meteorological) error in ambient ozone trends and uncertainty in the emission trend estimates. With respect to the former, 1975-1976 may have been a period of high meteorological pollution potential for ozone. With respect to the latter, there are three possibilities: (1) our overall estimates of NMHC and NO_x emission changes may be in error, (2) the NO_x emission increase may have occurred

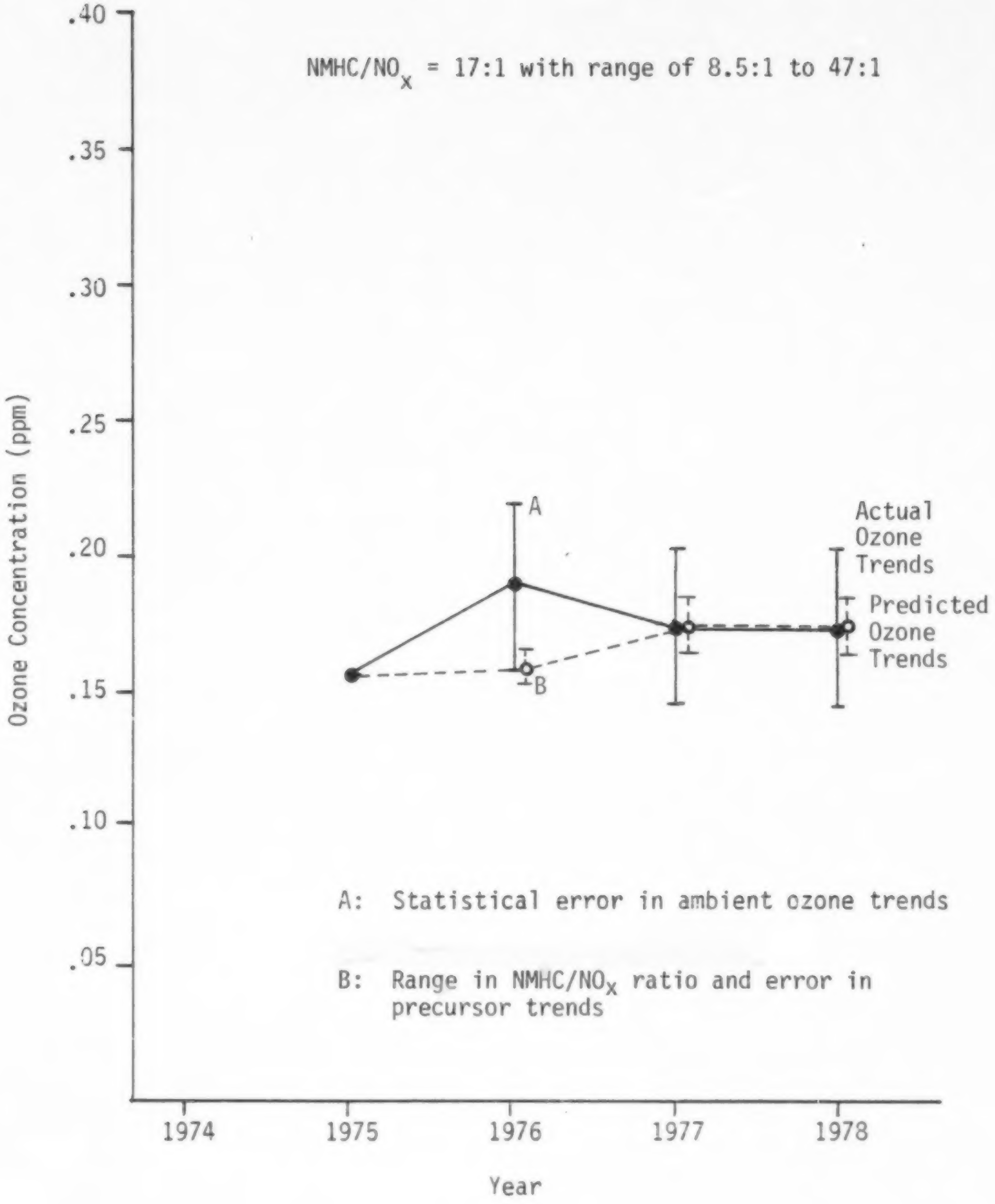

Figure 30. Summary of ozone trends for the 95th percentile of daily maxima at Aldine, predicted versus actual.

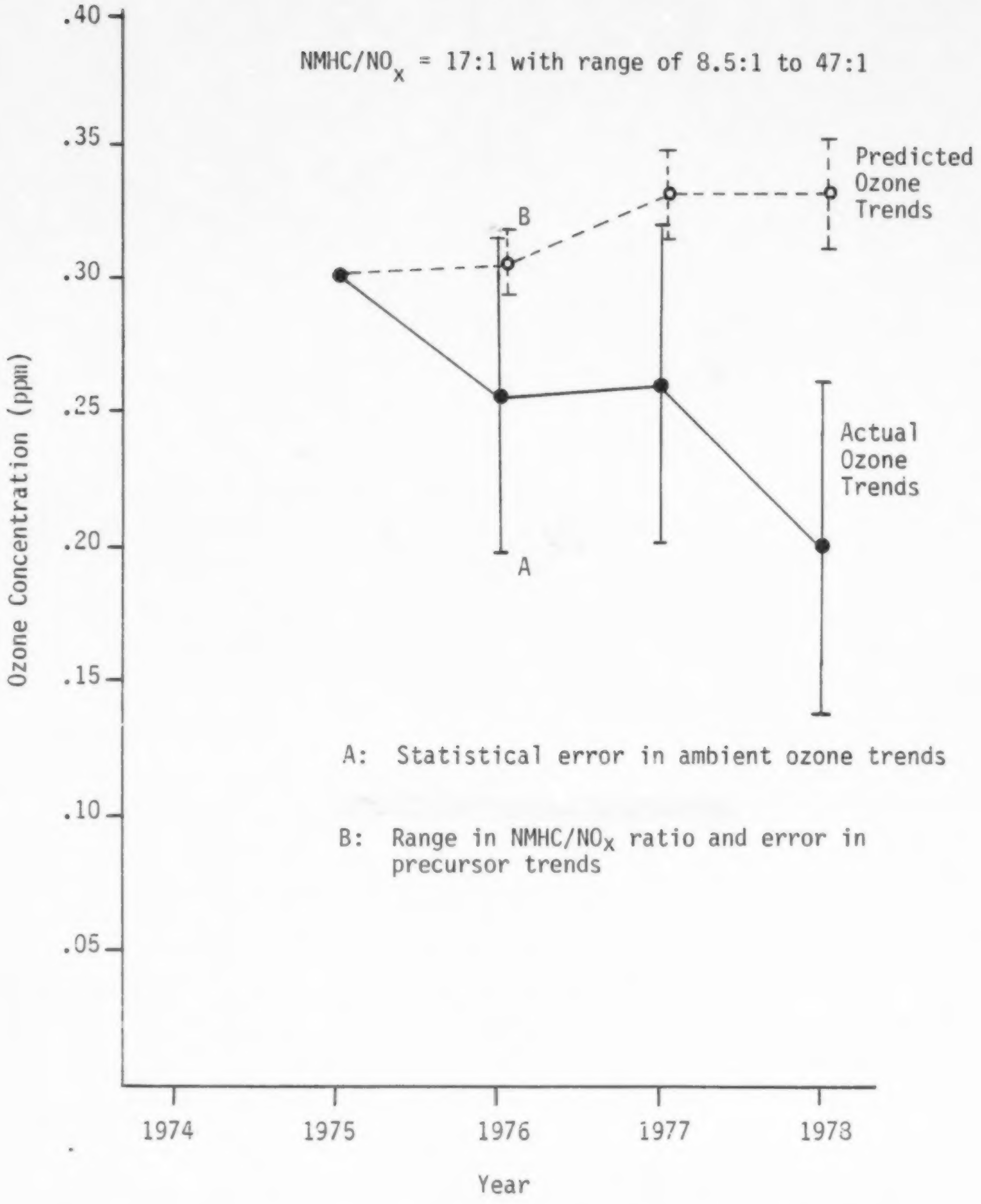

Figure 31. Summary of ozone trends for the yearly second maximum at Aldine, predicted versus actual.

somewhat earlier (i.e. relatively more in 1975-1976), and (3) some NMHC emission controls may have been installed somewhat later (i.e. relatively more in 1977-1978). Comparing the size of the error bounds on the actual trends and predicted trends (see Figures 28 to 30), the explanation more likely involves meteorological variance (i.e. high pollution potential in 1975-1976) than uncertainty in emission trends.

The above sources of error in our analysis may also account for some of the large discrepancy between predicted and actual trends in the yearly second maximum at Aldine. This large discrepancy (see Figure 31) might also be explained by anamolous behavior of the yearly second maximum at Aldine (i.e. by an extreme statistical error in this particular air quality index from 1975 to 1978 at Aldine). The anamolous behavior of the yearly second maximum at Aldine is highlighted in Table 12. Other ozone air quality indices at Aldine and all ozone air quality indices at Mae Drive showed little change from 1975 to 1978, but the yearly second maximum at Aldine decreased by 33%.

TABLE 12. NET CHANGE IN OZONE AIR QUALITY AT MAE DRIVE AND ALDINE FROM 1975 TO 1978 FOR VARIOUS AIR QUALITY INDICES.

SITE	NET PERCENT CHANGE IN OZONE CONCENTRATIONS, 1975 TO 1978		
	Average of Daily 1-Hour Maxima for Smog-Season	95th Percentile of Daily Maxima for Smog-Season	Yearly Second Highest Value
Mae Drive	- 1%	-10%	-10%
Aldine	+10%	+11%	-33%

Given the rather large error bounds in our analysis, it is difficult to tell if there is any fault with the EKMA model itself. In fact, a major finding of this study is that emission changes in Houston from 1974 to 1978 were not large enough to provide an adequate test of the EKMA model.

As a final remark, it is worthwhile to compare our results to previous ozone trends studies in Houston. Tannahill (1976) and Radian Corporation (1977) noted that ozone levels increased somewhat at Mae Drive and Aldine from 1974 to 1976 despite a stringent control program on NMHC emissions from stationary sources. This led to a paradox: "Why didn't ozone levels in Houston decrease when hydrocarbon emissions were reduced by about 20 to 35%?" Our analysis explains this paradox. For one, the increase in Houston ozone from 1974 to 1976 seems to have been a temporary aberration; ozone levels came back down in 1977 and 1978. Also, the decrease in hydrocarbon emissions was only 12% in Harris County (15% over the entire study region) from 1974 to 1975 and 1% in Harris County (2% over the entire study region) from 1975 to 1976.[*] The NMHC emission decrease was not as much as had been anticipated because many of the hydrocarbon controls were installed before 1974, because fugitive (uncontrolled) emissions were more important than previously thought, and because growth in source activity was very strong in the Houston area.

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[*] The emission changes reported by Radian (1977) evidently came from the 1973 and 1975 TACB inventories; these two inventories have different foundations and should not be used to analyze trends. Tannahill's (1976) emission trends came from "projected emission growth rates and emission reductions required by specific emission schedules". Our results are expected to differ from Tannahill's because we accounted for the fact that many controls (e.g. floating roof tanks) were installed _before_ they were required by compliance schedules, and because we used _newer_ data for fugitive emissions, motor vehicles, and other sources.

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APPENDIX A

DETAILED DESCRIPTION OF EMISSION TREND CALCULATIONS

This appendix describes our analysis of historical emission trends for NMHC and NO_x in the Houston area. The discussion covers the assumptions made and the methods used in estimating emissions for each source type and for each of the geographical areas considered.

GENERAL APPROACH

Tables A-1 through A-14 present NMHC and NO_x emission trends for the the entire Houston study region and for six sub-areas of the study region. Each numerical entry in these tables is the result of a multiplication of three factors: a volume factor (e.g. production for the year, miles traveled, or fuel used), an uncontrolled emission factor (tons of pollutant per volume), and a control factor. Each of these factors carries with it some uncertainty.

The volume data used were obtained from the publications of many agencies: Texas Air Control Board, U.S. Bureau of Mines, United States Department of Energy, Texas Railroad Commission, Texas Department of Highways and Public Transportation, and others. Volume figures for the chemical industry, the most difficult to obtain, came from the chemical industry publications "Oil and Gas Journal" and "Chemical Week". For several source categories, volume data were unavailable for 1978. In these cases the available data were regressed against several parameters (e.g. date, population, etc.), and the parameter most correlated with the existing data was used to predict the missing data.

Most of the uncontrolled emission factors we used came either from AP-42 Compilation of Air Pollution Emissions Factors (EPA 1977), or from An Analysis of Alternative Policies for Dealing with New Source Growth in Nonattainment Areas, Volume II: Oxidants/Study Area: Houston-Galveston AQCR (Engineering Science 1978). Indeed, we used the Engineering Science 1975 inventory as a base year inventory for many source categories. These 1975

TABLE A-1. NONMETHANE HYDROCARBON EMISSION TRENDS FOR THE ENTIRE STUDY REGION.

SOURCE CATEGORY	NMHC EMISSIONS (1000 TONS/YEAR)					
	1973	1974	1975	1976	1977	1978
STATIONARY POINT SOURCES						
Petroleum Refining	103.7	90.4	88.7	89.3	100.3	99.7
Natural Gas Processing	1.9	1.6	1.7	1.6	1.3	1.3
Chemical Industry	150.5	138.5	80.7	68.9	98.1	91.3
Other Point Sources	13.4	13.7	14.2	14.6	15.1	15.5
STATIONARY AREA SOURCES						
Paving	1.4	1.4	1.6	1.7	1.8	1.9
Gasoline Marketing	9.1	9.0	9.7	10.4	11.2	11.9
Industrial Painting	4.7	4.9	5.1	5.2	5.3	5.5
Degreasing and Solvents	9.6	9.9	10.2	10.5	10.8	11.1
Drycleaning	2.4	2.4	2.4	2.4	2.4	2.4
Com/Res Painting	2.5	1.7	1.2	1.2	1.3	1.2
Fuel Burning	0.9	1.0	1.1	1.1	1.1	1.2
MOBILE SOURCES						
Motor Vehicles						
Passenger Cars	70.1	69.3	68.1	68.2	66.0	66.1
Light Duty Trucks	20.2	21.4	22.9	23.9	25.3	26.2
Heavy Duty, Gas	9.8	12.7	10.2	11.6	12.9	14.2
Heavy Duty, Diesel	0.3	0.4	0.5	0.7	0.7	0.8
Motorcycles	0.9	0.9	0.9	0.9	0.9	0.9
Off-Road Vehicles	2.9	3.0	3.1	3.3	3.4	3.4
Other Transportation						
Trains	0.9	0.9	0.9	0.9	0.9	0.9
Airplanes	1.6	1.7	1.8	1.9	2.0	2.2
Boats	2.5	2.5	2.5	2.6	2.7	2.8
TOTAL	409.3	387.3	327.5	320.9	363.5	360.5

TABLE A-2. NONMETHANE HYDROCARBON EMISSION TRENDS FOR THE SHIP CHANNEL AREA.

SOURCE CATEGORY	NMHC EMISSIONS (1000 TONS/YEAR)					
	1973	1974	1975	1976	1977	1978
STATIONARY POINT SOURCES						
Petroleum Refining	58.9	49.8	49.1	50.2	61.8	60.1
Natural Gas Processing	0.1	0.1	0.1	0.1	0.0	0.0
Chemical Industry	70.3	64.7	37.7	32.2	56.0	49.3
Other Point Sources	2.3	2.4	2.5	2.5	2.6	2.7
STATIONARY AREA SOURCES						
Paving	0.0	0.1	0.1	0.1	0.1	0.1
Gasoline Marketing	0.3	0.3	0.3	0.4	0.4	0.4
Industrial Painting	0.7	0.8	0.8	0.8	0.8	0.9
Degreasing and Solvents	1.4	1.4	1.5	1.5	1.6	1.6
Drycleaning	0.1	0.1	0.1	0.1	0.1	0.1
Com/Res Painting	0.1	0.0	0.0	0.0	0.0	0.0
Fuel Burning	0.0	0.0	0.0	0.0	0.0	0.0
MOBILE SOURCES						
Motor Vehicles						
Passenger Cars	2.6	2.4	2.4	2.5	2.4	2.4
Light Duty Trucks	0.8	0.9	0.9	1.0	1.0	1.0
Heavy Duty, Gas	0.2	0.2	0.2	0.2	0.2	0.2
Heavy Duty, Diesel	0.0	0.0	0.0	0.0	0.0	0.0
Motorcycles	0.1	0.1	0.1	0.1	0.1	0.1
Off-Road Vehicles	0.0	0.0	0.0	0.0	0.0	0.0
Other Transportation						
Trains	0.0	0.0	0.0	0.0	0.0	0.0
Airplanes	0.0	0.0	0.0	0.0	0.0	0.0
Boats	1.2	1.2	1.2	1.3	1.3	1.4
TOTAL	139.1	124.5	97.0	93.0	128.4	120.3

TABLE A-3. NONMEHTANE HYDROCARBON EMISSION TRENDS FOR THE HOUSTON CITY AREA (EXCLUDING THE SHIP CHANNEL AREA).

SOURCE CATEGORY	NMHC EMISSIONS (1000 TONS/YEAR)					
	1973	1974	1975	1976	1977	1978
STATIONARY POINT SOURCES						
Petroleum Refining	0.0	0.0	0.0	0.0	0.0	0.0
Natural Gas Processing	0.7	0.6	0.6	0.6	0.5	0.5
Chemical Industry	11.3	10.4	6.1	5.2	9.0	7.9
Other Point Sources	10.7	11.0	11.3	11.7	12.0	12.3
STATIONARY AREA SOURCES						
Paving	1.0	1.0	1.0	1.1	1.2	1.3
Gasoline Marketing	6.3	6.2	6.5	7.1	7.5	8.0
Industrial Painting	3.4	3.5	3.6	3.7	3.8	3.9
Degreasing and Solvents	6.4	6.6	6.8	7.0	7.3	7.5
Drycleaning	1.4	1.4	1.5	1.4	1.4	1.4
Com/Res Painting	1.5	1.0	0.7	0.7	0.7	0.7
Fuel Burning	0.6	0.6	0.6	0.6	0.6	0.7
MOBILE SOURCES						
Motor Vehicles						
Passenger Cars	49.7	49.9	47.3	48.8	46.3	45.9
Light Duty Trucks	13.5	14.2	15.8	16.3	17.1	17.7
Heavy Duty, Gas	6.7	9.1	6.8	7.9	8.9	9.6
Heavy Duty, Diesel	0.2	0.3	0.4	0.5	0.5	0.6
Motorcycles	0.1	0.1	0.1	0.2	0.2	0.2
Off-Road Vehicles	0.0	0.0	0.0	0.0	0.0	0.0
Other Transportation						
Trains	0.5	0.5	0.5	0.5	0.5	0.5
Airplanes	1.6	1.7	1.8	1.9	2.0	2.2
Boats	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	115.6	118.1	111.4	115.2	119.5	120.9

TABLE A-4. NONMETHANE HYDROCARBON EMISSION TRENDS FOR THE REMAINDER OF HARRIS COUNTY.

SOURCE CATEGORY	NMHC EMISSIONS (1000 TONS/YEAR)					
	1973	1974	1975	1976	1977	1978
STATIONARY POINT SOURCES						
Petroleum Refining	0.0	0.0	0.0	0.0	0.0	0.0
Natural Gas Processing	0.0	0.0	0.0	0.0	0.0	0.0
Chemical Industry	0.0	0.0	0.0	0.0	0.0	0.0
Other Point Sources	0.0	0.0	0.0	0.0	0.0	0.0
STATIONARY AREA SOURCES						
Paving	0.2	0.2	0.3	0.3	0.3	0.3
Gasoline Marketing	1.4	1.4	1.6	1.6	1.9	2.0
Industrial Painting	0.0	0.0	0.0	0.0	0.0	0.0
Degreasing and Solvents	0.0	0.0	0.0	0.0	0.0	0.0
Drycleaning	0.6	0.6	0.6	0.6	0.6	0.6
Com/Res Painting	0.6	0.4	0.3	0.3	0.3	0.3
Fuel Burning	0.2	0.2	0.3	0.3	0.3	0.3
MOBILE SOURCES						
Motor Vehicles						
Passenger Cars	9.8	9.5	10.4	9.1	9.4	9.9
Light Duty Trucks	3.0	3.2	3.4	3.1	3.5	3.8
Heavy Duty, Gas	1.8	2.0	1.9	2.0	2.3	2.7
Heavy Duty, Diesel	0.1	0.1	0.1	0.2	0.2	0.2
Motorcycles	0.2	0.3	0.3	0.3	0.4	0.4
Off-Road Vehicles	2.4	2.5	2.6	2.7	2.8	2.8
Other Transportation						
Trains	0.1	0.1	0.1	0.1	0.1	0.1
Airplanes	0.0	0.0	0.0	0.0	0.0	0.0
Boats	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	20.5	20.5	21.9	20.6	22.1	23.4

TABLE A-5. NONMETHANE HYDROCARBON EMISSION TRENDS FOR HARRIS COUNTY TOTAL.

SOURCE CATEGORY	NMHC EMISSIONS (1000 TONS/YEAR)					
	1973	1974	1975	1976	1977	1978
STATIONARY POINT SOURCES						
Petroleum Refining	58.9	49.8	49.1	50.2	61.8	60.1
Natural Gas Processing	0.8	0.7	0.7	0.7	0.5	0.5
Chemical Industry	81.6	75.1	43.7	37.3	65.0	57.2
Other Point Sources	13.0	13.4	13.8	14.2	14.6	15.0
STATIONARY AREA SOURCES						
Paving	1.2	1.2	1.4	1.5	1.6	1.7
Gasoline Marketing	8.0	7.9	8.5	9.1	9.8	10.4
Industrial Painting	4.1	4.2	4.4	4.5	4.6	4.8
Degreasing and Solvents	7.8	8.1	8.3	8.5	8.8	9.1
Drycleaning	2.1	2.1	2.1	2.1	2.1	2.1
Com/Res Painting	2.2	1.5	1.0	1.0	1.1	1.0
Fuel Burning	0.8	0.8	0.9	0.9	0.9	1.0
MOBILE SOURCES						
Motor Vehicles						
Passenger Cars	61.7	61.6	60.1	60.2	58.0	58.2
Light Duty Trucks	17.4	18.4	20.0	20.5	21.7	22.5
Heavy Duty, Gas	8.9	11.3	8.9	10.2	11.5	12.6
Heavy Duty, Diesel	0.3	0.4	0.5	0.7	0.7	0.8
Motorcycles	0.6	0.6	0.6	0.6	0.6	0.6
Off-Road Vehicles	2.4	2.5	2.6	2.7	2.8	2.8
Other Transportation						
Trains	0.6	0.6	0.6	0.6	0.6	0.6
Airplanes	1.6	1.7	1.8	1.9	2.0	2.2
Boats	1.2	1.2	1.2	1.3	1.3	1.4
TOTAL	275.2	263.1	230.2	228.7	270.0	264.6

TABLE A-6. NONMETHANE HYDROCARBON EMISSION TRENDS FOR BRAZORIA COUNTY.

SOURCE CATEGORY	NMHC EMISSIONS (1000 TONS/YEAR)					
	1973	1974	1975	1976	1977	1978
STATIONARY POINT SOURCES						
Petroleum Refining	6.1	5.4	5.3	5.9	4.6	5.2
Natural Gas Processing	1.0	0.8	0.9	0.8	0.7	0.7
Chemical Industry	47.4	43.6	25.4	21.7	20.9	23.2
Other Point Sources	0.0	0.0	0.0	0.0	0.0	0.0
STATIONARY AREA SOURCES						
Paving	0.1	0.1	0.1	0.1	0.1	0.1
Gasoline Marketing	0.5	0.5	0.5	0.6	0.6	0.7
Industrial Painting	0.3	0.3	0.3	0.3	0.3	0.3
Degreasing and Solvents	0.9	0.9	0.9	1.0	1.0	1.0
Drycleaning	0.1	0.1	0.1	0.1	0.1	0.1
Com/Res Painting	0.1	0.1	0.1	0.1	0.1	0.1
Fuel Burning	0.0	0.1	0.1	0.1	0.1	0.1
MOBILE SOURCES						
Motor Vehicles						
Passenger Cars	3.5	3.2	3.4	3.3	3.2	3.1
Light Duty Trucks	1.4	1.5	1.4	1.7	1.8	1.8
Heavy Duty, Gas	0.7	0.9	0.8	0.9	0.9	1.0
Heavy Duty, Diesel	0.0	0.0	0.0	0.0	0.0	0.0
Motorcycles	0.1	0.1	0.1	0.1	0.1	0.1
Off-Road Vehicles	0.3	0.3	0.3	0.3	0.3	0.3
Other Transportation						
Trains	0.1	0.1	0.1	0.1	0.1	0.1
Airplanes	0.0	0.0	0.0	0.0	0.0	0.0
Boats	0.3	0.3	0.3	0.3	0.3	0.3
TOTAL	62.9	58.3	40.1	37.4	35.2	38.2

TABLE A-7. NONMETHANE HYDROCARBON EMISSION TRENDS FOR GALVESTON COUNTY.

SOURCE CATEGORY	NMHC EMISSIONS (1000 TONS/YEAR)					
	1973	1974	1975	1976	1977	1978
STATIONARY POINT SOURCES						
Petroleum Refining	38.7	35.2	34.3	33.2	33.8	34.3
Natural Gas Processing	0.1	0.1	0.1	0.1	0.1	0.1
Chemical Industry	21.6	19.8	11.6	9.9	12.3	10.9
Other Point Sources	0.4	0.5	0.5	0.5	0.5	0.5
STATIONARY AREA SOURCES						
Paving	0.1	0.1	0.1	0.1	0.1	0.1
Gasoline Marketing	0.6	0.6	0.7	0.7	0.8	0.8
Industrial Painting	0.3	0.4	0.4	0.4	0.4	0.4
Degreasing and Solvents	0.9	0.9	1.0	1.0	1.0	1.0
Drycleaning	0.2	0.2	0.2	0.2	0.2	0.2
Com/Res Painting	0.2	0.1	0.1	0.1	0.1	0.1
Fuel Burning	0.1	0.1	0.1	0.1	0.1	0.1
MOBILE SOURCES						
Motor Vehicles						
Passenger Cars	4.9	4.5	4.6	4.7	4.8	4.8
Light Duty Trucks	1.4	1.5	1.5	1.7	1.8	1.9
Heavy Duty, Gas	0.2	0.5	0.5	0.5	0.5	0.6
Heavy Duty, Diesel	0.0	0.0	0.0	0.0	0.0	0.0
Motorcycles	0.2	0.2	0.2	0.2	0.2	0.2
Off-Road Vehicles	0.2	0.2	0.2	0.3	0.3	0.3
Other Transportation						
Trains	0.2	0.2	0.2	0.2	0.2	0.2
Airplanes	0.0	0.0	0.0	0.0	0.0	0.0
Boats	1.0	1.0	1.0	1.0	1.1	1.1
TOTAL	71.3	66.1	57.3	54.9	58.3	57.6

TABLE A-8. NITROGEN OXIDE EMISSIONS TRENDS FOR THE ENTIRE STUDY REGION.

SOURCE CATEGORY	NO_x EMISSIONS (1000 TONS/YEAR)					
	1973	1974	1975	1976	1977	1978
STATIONARY POINT SOURCES						
Petroleum Refineries	42.5	41.8	44.8	45.1	48.9	50.5
Natural Gas Refineries	12.8	11.4	11.5	10.9	10.0	9.4
Chemical Industry	62.4	62.4	54.9	64.5	80.3	89.1
Power Plants	41.8	44.8	44.5	46.6	50.6	51.5
Other Point Sources	9.5	10.0	10.4	10.8	11.3	11.5
STATIONARY AREA SOURCES						
Fuel Burning	5.1	5.3	5.5	5.7	6.0	6.1
MOBILE SOURCES						
Motor Vehicles						
Passenger Cars	53.3	52.3	52.5	53.3	50.6	49.2
Light Duty Trucks	13.7	14.9	16.3	17.5	18.3	19.5
Heavy Duty, Gas	8.9	11.4	9,3	10.8	11.7	12.5
Heavy Duty, Diesel	2.7	3.1	4.1	5.3	5.5	6.2
Motorcycles	0.0	0.0	0.0	0.0	0.0	0.0
Off-Road Vehicles	7.2	7.5	7.7	8.0	8.2	8.4
Other Transportation						
Trains	3.6	3.6	3.6	3.6	3.6	3.6
Airplanes	1.1	1.2	1.3	1.4	1.5	1.6
Boats	3.7	3.8	3.9	4.0	4.2	4.2
TOTAL	268.3	273.5	270.3	287.5	310.7	323.3

TABLE A-9. NITROGEN OXIDE EMISSION TRENDS FOR THE SHIP CHANNEL AREA.

SOURCE CATEGORY	NO_x EMISSIONS (1000 TONS/YEAR)					
	1973	1974	1975	1976	1977	1978
STATIONARY POINT SOURCES						
Petroleum Refineries	19.9	18.9	20.5	20.5	26.0	25.2
Natural Gas Refineries	0.5	0.4	0.4	0.4	0.4	0.3
Chemical Industry	12.3	12.3	10.8	12.7	22.9	22.5
Power Plants	3.3	2.7	3.8	3.1	3.4	3.5
Other Point Sources	1.3	1.2	1.4	1.4	1.5	1.5
STATIONARY AREA SOURCES						
Fuel Burning	0.1	0.1	0.2	0.2	0.2	0.2
MOBILE SOURCES						
Motor Vehicles						
Passenger Cars	1.8	1.7	1.8	1.9	1.7	1.8
Light Duty Trucks	0.5	0.6	0.6	0.6	0.7	0.7
Heavy Duty, Gas	0.2	0.2	0.2	0.2	0.2	0.2
Heavy Duty, Diesel	0.1	0.1	0.1	0.1	0.1	0.1
Motorcycles	0.0	0.0	0.0	0.0	0.0	0.0
Off-Road Transportation	0.0	0.0	0.0	0.0	0.0	0.0
Other Transportation						
Trains	0.1	0.1	0.1	0.1	0.1	0.1
Airplanes	0.0	0.0	0.0	0.0	0.0	0.0
Boats	1.4	1.4	1.5	1.5	1.6	1.6
TOTAL	41.5	39.7	41.4	42.7	58.8	57.7

TABLE A-10. NITROGEN OXIDE EMISSION TRENDS FOR
THE HOUSTON CITY AREA (EXCLUDING
THE SHIP CHANNEL AREA).

SOURCE CATEGORY	NO_x EMISSIONS (1000 TONS/YEAR)					
	1973	1974	1975	1976	1977	1978
STATIONARY POINT SOURCES						
Petroleum Refineries	0.0	0.0	0.0	0.0	0.0	0.0
Natural Gas Refineries	4.8	4.3	4.3	4.1	3.8	3.5
Chemical Industry	3.4	3.4	3.0	3.5	6.4	6.3
Power Plants	15.5	13.5	14.0	16.1	17.5	18.1
Other Point Sources	8.2	8.6	8.9	9.3	9.7	9.9
STATIONARY AREA SOURCES						
Fuel Burning	3.1	3.2	3.2	3.4	3.5	3.6
MOBILE SOURCES						
Motor Vehicles						
Passenger Cars	36.6	36.5	35.2	36.4	34.2	33.2
Light Duty Trucks	9.1	9.7	11.0	11.6	12.0	12.8
Heavy Duty, Gas	5.5	7.8	6.0	7.0	7.5	8.0
Heavy Duty, Diesel	1.8	2.2	2.7	3.5	3.5	4.0
Motorcycles	0.0	0.0	0.0	0.0	0.0	0.0
Off-Road Vehicles	0.0	0.0	0.0	0.0	0.0	0.0
Other Transportation						
Trains	2.0	2.0	2.0	2.0	2.0	2.0
Airplanes	1.1	1.2	1.3	1.4	1.5	1.6
Boats	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	91.1	92.4	91.6	98.3	101.6	103.0

TABLE A-11. NITROGEN OXIDE EMISSION TRENDS FOR THE REMAINDER OF HARRIS COUNTY.

SOURCE CATEGORY	NO_x EMISSIONS (1000 TONS/YEAR)					
	1973	1974	1975	1976	1977	1978
STATIONARY POINT SOURCES						
Petroleum Refineries	0.0	0.0	0.0	0.0	0.0	0.0
Natural Gas Refineries	0.0	0.0	0.0	0.0	0.0	0.0
Chemical Industry	0.0	0.0	0.0	0.0	0.0	0.0
Power Plants	5.4	3.5	4.2	5.4	5.0	5.2
Other Point Sources	0.0	0.0	0.0	0.0	0.0	0.0
STATIONARY AREA SOURCES						
Fuel Burning	1.2	1.3	1.4	1.4	1.5	1.6
MOBILE SOURCES						
Motor Vehicles						
Passenger Cars	8.0	7.7	8.5	8.2	8.3	8.0
Light Duty Trucks	2.2	2.4	2.6	2.5	3.0	3.1
Heavy Duty, Gas	2.2	2.1	1.9	2.2	2.4	2.7
Heavy Duty, Diesel	0.6	0.6	1.0	1.1	1.4	1.6
Motorcycles	0.0	0.0	0.0	0.0	0.0	0.0
Off-Road Vehicles	5.7	5.9	6.1	6.3	6.5	6.7
Other Transportation						
Trains	0.4	0.4	0.4	0.4	0.4	0.4
Airplanes	0.0	0.0	0.0	0.0	0.0	0.0
Boats	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	25.7	23.9	26.1	27.5	28.5	29.3

TABLE A-12. NITROGEN OXIDE EMISSION TRENDS FOR HARRIS COUNTY TOTAL.

SOURCE CATEGORY	NO_x EMISSIONS (1000 TONS/YEAR)					
	1973	1974	1975	1976	1977	1978
STATIONARY POINT SOURCES						
Petroleum Refineries	19.9	18.9	20.5	20.5	26.0	25.2
Natural Gas Refineries	5.3	4.8	4.7	4.5	4.2	3.9
Chemical Industry	15.7	15.7	13.8	16.2	29.3	28.9
Power Plants	24.2	19.6	22.0	24.6	25.9	26.8
Other Point Sources	9.5	9.9	10.2	10.7	11.2	11.4
STATIONARY AREA SOURCES						
Fuel Burning	4.4	4.6	4.8	5.0	5.2	5.3
MOBILE SOURCES						
Motor Vehicles						
Passenger Cars	46.2	45.9	45.6	46.3	44.1	42.9
Light Duty Trucks	11.8	12.8	14.2	14.8	15.7	16.6
Heavy Duty, Gas	8.1	10.0	8.1	9.4	10.2	11.0
Heavy Duty, Diesel	2.5	2.9	3.7	4.8	5.0	5.7
Motorcycles	0.0	0.0	0.0	0.0	0.0	0.0
Off-Road Vehicles	5.7	5.9	6.1	6.3	6.5	6.7
Other Transportation						
Trains	2.5	2.5	2.5	2.5	2.5	2.5
Airplanes	1.1	1.2	1.3	1.4	1.5	1.6
Boats	1.4	1.4	1.5	1.5	1.6	1.6
TOTAL	158.3	156.1	159.0	168.5	188.9	190.1

TABLE A-13. NITROGEN OXIDE EMISSION TRENDS FOR BRAZORIA.

SOURCE CATEGORY	NO_x EMISSIONS (1000 TONS/YEAR)					
	1973	1974	1975	1976	1977	1978
STATIONARY POINT SOURCES						
Petroleum Refineries	9.8	9.7	10.3	11.4	9.4	11.5
Natural Gas Refineries	7.0	6.2	6.3	6.0	5.4	5.1
Chemical Industry	37.5	37.5	33.0	38.7	38.7	48.1
Power Plants	0.0	0.0	0.0	0.0	0.0	0.0
Other Point Sources	0.0	0.1	0.1	0.1	0.1	0.1
STATIONARY AREA SOURCES						
Fuel Burning	0.3	0.3	0.3	0.3	0.3	0.3
MOBILE SOURCES						
Motor Vehicles						
Passenger Cars	3.0	2.7	2.9	2.7	2.6	2.5
Light Duty Trucks	1.0	1.1	1.1	1.4	1.3	1.5
Heavy Duty, Gas	0.7	0.9	0.8	0.9	1.0	1.0
Heavy Duty, Diesel	0.1	0.1	0.2	0.2	0.3	0.3
Motorcycles	0.0	0.0	0.0	0.0	0.0	0.0
Off-Road Transportation	0.9	0.9	1.0	1.0	1.0	1.0
Other Transportation						
Trains	0.4	0.4	0.4	0.4	0.4	0.4
Airplanes	0.0	0.0	0.0	0.0	0.0	0.0
Boats	0.5	0.5	0.5	0.6	0.6	0.6
TOTAL	61.2	60.4	56.9	63.7	61.1	72.4

TABLE A-14. NITROGEN OXIDE EMISSION TRENDS FOR GALVESTON.

SOURCE CATEGORY	NO_x EMISSIONS (1000 TONS/YEAR)					
	1973	1974	1975	1976	1977	1978
STATIONARY POINT SOURCES						
Petroleum Refineries	12.8	13.1	14.0	13.1	13.5	13.8
Natural Gas Refineries	0.5	0.4	0.4	0.4	0.4	0.4
Chemical Industry	9.2	9.2	8.1	9.5	12.3	12.2
Power Plants	17.6	25.2	22.5	22.0	24.7	24.7
Other Point Sources	0.0	0.0	0.0	0.0	0.0	0.0
STATIONARY AREA SOURCES						
Fuel Burning	0.4	0.4	0.4	0.4	0.5	0.5
MOBILE SOURCES						
Motor Vehicles						
Passenger Cars	4.1	3.7	4.0	4.3	3.9	3.8
Light Duty Trucks	0.9	1.0	1.0	1.3	1.3	1.4
Heavy Duty, Gas	0.1	0.5	0.4	0.5	0.5	0.5
Heavy Duty, Diesel	0.1	0.1	0.2	0.3	0.2	0.2
Motorcycles	0.0	0.0	0.0	0.0	0.0	0.0
Off-Road Vehicles	0.6	0.6	0.6	0.7	0.7	0.7
Other Transportation						
Trains	0.7	0.7	0.7	0.7	0.7	0.7
Airplanes	0.0	0.0	0.0	0.0	0.0	0.0
Boats	1.8	1.8	1.9	1.9	2.0	2.0
TOTAL	48.8	56.7	54.2	55.1	60.7	60.9

emissions were projected forward and backward in time taking into consideration changing volumes and control factors.

Particularly troublesome source categories with respect to uncontrolled emission factors for NMHC are petroleum refineries and chemical plants which constitute a large portion of the emission inventory in the Houston-Galveston area. It is not clear how to make the best estimate of an overall, volume-dependent NMHC emission factor when these refineries and plants emit hydrocarbons at different rates from thousands of valves from a variable number of refining processes. For the petroleum industry, we adjusted our uncontrolled emission factors slightly so that our 1977 emissions match the emissions listed in "Aerometric Data Analysis for the Houston Area Oxidant Study" (SRI 1979). This report, called the HAOS study, is considered to contain the most accurate point source inventory of the area. We also used the HAOS study to provide a base year NMHC inventory for the chemical industry.

The application of emission controls to many processes (especially to chemical processing and the loading/storage of petroleum and petroleum products) introduces another uncertainty into our estimation of emissions. In order to represent the effectiveness of these controls on each source type and during each year, we used the Texas Air Control Board's estimate (TACB 1978c) of the number of tons of hydrocarbons collected by the added controls over the years 1973 to 1977 and the percentage of these controls applied each year. From these estimates we constructed control schedules which will be listed by source type later in this Appendix. The control schedules were used only on the volume of production listed for 1973. All growth after 1973 was assumed to have the full degree of control attained by 1978.

While it is true that the uncertainty in the emission trends varies among source types, nitrogen oxides were fairly simple to handle because the emissions from many source categories are well understood and because essentially no NO_x controls have been applied during the study period (except in the case of transportation sources). We did, however, include a conservation factor to account for the progress made by the chemical and petroleum industries in conserving fuel. For a base year point source inventory, we again used the HAOS point source list (SRI 1979) and the emission levels reported there. These were factored according to volume (corrected for fuel conservation) to determine the point source trends for nitrogen oxides.

STATIONARY NITROGEN OXIDE SOURCES

Power plant emissions were calculated by considering each operating plant separately. The emission factors and fuel usage trends for each plant were determined from information reported by DOE (1973, 1973-1977). The emission factor and fuel usage data were combined to calculate yearly emissions.

The NO_x generated by the chemical and petroleum industries was calculated by using the HAOS point source list (SRI 1979) for 1977 as a base year. Both of these industries achieved a reduction in fuel use per pound-of-product-processed over the years 1972 to 1980. TACB personnel (Roeser 1980) report that all companies reduced fuel usage per pound-of-product-processed by 15%. Some reduced it by 25 or 30%. Although a reduction in fuel use does not necessarily mean a proportional reduction in NO_x emissions (see Appendix B for a discussion of this point), we assumed a 20% reduction in NO_x emissions per pound-of-product applied linearly over those years. Growth data for the chemical and petroleum industries are discussed later in the hydrocarbon section of this appendix.

The NO_x emissions from natural gas refineries and other point sources were estimated by using the TACB's point source list (TACB 1978a) with 1973 as a base year and then factoring by a volume figure. For natural gas refineries, actual year by year throughput was used for the volume factor. For other point sources, population was used for volume.

Emissions from residential, commercial, and industrial burning of fuels were taken directly from TACB's yearly area source inventories (TACB 1978b).

TRANSPORTATION SOURCES

Hydrocarbon and nitrogen oxide emission factors for autos, trucks, and motorcycles were constructed using the method outlined in AP-42, but with the newer emission factors reported in Mobile Source Emission Factors (EPA 1978). In our calculations, we accounted for (1) the decrease in average speed reported by H-GRTS (1977), (2) variations in average speed by road type estimated by the Texas State Department of Highways and Public Transportation (1978), (3) variations in traffic volume by road type for each county reported by H-GRTS (1974-1978), (4) variations in vehicle type/age mixes by county compiled by the Texas State Department of Highways and Public Transportation and by the Texas Motor Vehicle Commission, and (5) the percent nonmethane hydrocarbons from transportation sources reported in "Utility of Reactivity Criteria in Organic Emission Control Strategies" (Trijonis and Arledge 1976).

Off-road vehicle emissions and emissions from trains, boats, and airplanes are those reported in the TACB's yearly area source inventories (TACB 1978b).

STATIONARY HYDROCARBON SOURCES

Petroleum Industry

Hydrocarbon emissions from the petroleum industry are the result of several activities: petroleum processing, refinery storage, crude storage, refinery loading, and crude loading. We elected to use the HAOS inventory (SRI 1979) as a base year inventory for this category. Even in preliminary form (Walker 1980), this inventory lumps all these activities together. We calculated emissions for each category (processing, refinery storage, crude storage, refinery loading, and crude loading) by the methods outlined in the following discussion. We totaled these emissions and adjusted them slightly (factored by an average of 1.2) so that the total matched the HAOS inventory (SRI 1979) in 1977.

Processing

Two emissions factors were used to determine the hydrocarbon emission rate from petroleum refineries: (1) a capacity dependent factor and (2) a throughput dependent factor. The capacity dependent number represents cooling tower losses and fugitive emissions from pumps and valves. We increased

Engineering Science's (1978) emission factor for valve losses by a factor of three to reflect the results published in Emission Factors and Frequency of Leak Occurrence for Fittings in Refinery Process Units (Wetherold et al. 1979). For the other capacity dependent emissions, we used the Engineering Science (1978) factors and found them to agree with the factors listed in several other references (EPA 1977; Wetherold et al. 1979; Taback 1978). These factors were combined to give one capacity dependent factor, 63.0 tons/year per 10^6 bbls/year capacity, representing mostly fugitive emissions.

Controls have been applied to the cracking units and to other throughput processes. Using the emissions reported by Engineering Science (1978) and the control schedule suggested by the TACB, we arrived at an uncontrolled emission factor of 12.2 tons per 10^6 bbls throughput.

The following capacity schedule, throughput schedule, and control schedule produced our total trends in petroleum processing in the region.

YEAR	1973	1974	1975	1976	1977	1978
Refinery Processing Capacity, 10^6 bbls/yr	591	580	588	642	756	741
Throughput, 10^6 bbls/yr	476	476	526	534	645	660
Control Factor (throughput dependent emissions)	.99	.98	.93	.91	.90	.90

The capacity figures are from the Texas Railroad Commission Annual Report of the Oil and Gas Division (RRC 1972-1977). The refinery by refinery data listed there were used to specify the capacity by geographical area and to apportion the Bureau of Mines' "Crude Input, Texas Gulf" throughput by area (BOM 1973-1975, 1973-1978).

Storage -- Refinery and Crude

Taback et al. (1978) recently found that the AP-42 (EPA 1977) emission factors for petroleum storage tanks are too high. Taback et al. suggest that applying a .6 correction factor to the AP-42 numbers for both controlled and uncontrolled tanks will provide a more realistic estimate of storage emissions. Using their own emission factors, Engineering Science (1978) obtained a result that is .62 of TACB's AP-42 based estimate for this category. Therefore, we again used Engineering Science's inventory as our base.

Hydrocarbons are emitted from storage tanks while the petroleum product waits undisturbed in the tank (breathing loss), and while the material is being loaded or unloaded from the tank (working loss). The ratio of breathing loss (per amount stored) to working loss (per throughput) is a factor of 9 and remains fairly constant independent of the tank type and of the type of material stored (Engineering Science, 1978). Also apparently constant are the ratio of yearly refinery throughput to amount held in storage (ratio = 24) and the ratio of yearly production of crude to amount of crude in storage (ratio = 30) (RRC 1973-1978). It is possible, therefore, to construct one throughput or production related emission factor for both breathing and working losses.

For refinery storage the emissions are:

$$Q(2T + \frac{9T}{24}) \qquad \text{(A-1)}$$

where Q = working loss emission factor

T = yearly refinery throughput

The factor 2T is indicated because, according to AP-42, the petroleum undergoes working losses twice: once before and once after processing. We took Q = 63 tons for each 10^6 bbls of tank throughput; this corresponds to 70% gasoline in storage and 30% storage of other products. The uncontrolled emission factor by Equation A-1 is then 150 tons for each 10^6 bbls of refinery throughput. The control factor schedule and refinery throughput schedule we used is:

YEAR	1973	1974	1975	1976	1977	1978
Refinery Storage Control Factor	.39	.25	.21	.17	.16	.16
Volume (10^6 bbls/yr)	476	476	526	534	645	660

For crude production the emissions are:

$$Q = (P + \frac{9P}{30}) \qquad \text{(A-2)}$$

where Q = working loss emission factor

P = production

We used Q = 63 tons for each 10^6 bbls of tank throughput. This number is about 15% high compared to typical emission factors for uncontrolled crude storage, but it produces an inventory which matches Engineering Science's 1975 inventory and the control schedule suggested by the TACB. The production dependent emission factor for crude by Equation A-2 is 82 tons for each 10^6 bbls of crude produced. The schedule we used is:

YEAR	1973	1974	1975	1976	1977	1978
Crude Storage Control Factor	.39	.25	.21	.17	.16	.16
Volume (10^6 bbls/yr)	72.2	76.8	72.8	71.3	68.0	65.1

The crude production volume figures are from the Railroad Commission of Texas' Annual Report of the Oil and Gas Division (RRC 1972-1977).

The emissions from storage categories were geographically distributed in proportion to the geographical distribution of processing emissions for each category.

Loading -- Refinery and Crude

Some emission control has been achieved by using vapor recovery systems while loading petroleum and petroleum products. The overall loading control schedule suggested by the TACB is:

YEAR	1973	1974	1975	1976	1977	1978
Overall Loading Control Factor	.89	.83	.80	.78	.78	.78

This schedule was used when calculating emissions from loading crude oil and refinery products.

The uncontrolled emission factors for these categories were chosen so that answers match those listed in Engineering Science's 1975 inventory. The inventory for crude loading was developed from the Texas Railroad Commission's figures for crude production and an uncontrolled emission factor of 107 tons for every 10^6 bbls of crude oil produced. Emissions from gasoline and other product loading at refineries was taken to be proportional to refinery throughput according to the uncontrolled factor, 21 tons for each 10^6 bbls of throughput.

As stated earlier, emissions from all the refinery industry activities were added together and adjusted slightly so that, in each geographical area, the 1977 emission level is the same as that reported in the HAOS inventory (SRI 1979).

Chemical Industry

Hydrocarbon emissions for the chemical industry were estimated using the 1977 HAOS inventory (SRI 1979) as a base year inventory. Again we encountered the difficulty that the HAOS inventory lumps together several activities -- processing, storage, and loading. As described in subsequent subsections, we derived our own estimates of relative emissions for each of these three separate activities. We then apportioned the 1977 HAOS inventory for the chemical industry according to the relative emission factors for those activities that year.

The same growth schedule was applied to all three activities. The growth data were taken from two sources. For the years 1976 through 1978, a yearly plant-by-plant list of ethylene capacity (Oil and Gas Journal 1980) provided a geographically distributed indicator of growth. For the years 1973 through 1976, chemical production for each area was assumed to be proportional to total U.S. chemical production index given in Chemical Week (1973-1976).

To give the reader an idea of the total chemical industry growth in the Houston area, we have derived an overall growth schedule weighting the growth in each sub-area by the emissions in that sub-area. The aggregate areawide petrochemical growth schedule is then as follows:

YEAR	1973	1974	1975	1976	1977	1978
Petrochemical Growth	1.00	1.03	0.93	1.12	1.70	1.82

Processing

The processing emissions from chemical plants (as in the case of refineries) are considered to be partly fugitive and partly controllable. The fugitive factor was taken to be 400 tons per 10^6 bbls feedstock. This assumes that 24% of the emissions in 1975 are fugitive emissions -- again using Engineering Science's inventory for the 1975 emissions level. The uncontrolled emission factor for non-fugitive emissions is 2600 tons per 10^6 bbls of feedstock. The control schedule assumed for non-fugitive emissions is

YEAR	1973	1974	1975	1976	1977	1978
Petrochemical Processing Control Factor	.95	.86	.48	.28	.25	.20

Storage

Taking into account the fact that the ratio of breathing losses to working losses for chemical storage are about constant, we developed a single uncontrolled emission factor for chemical storage in a manner similar to that discussed previously for petroleum storage. This factor worked out to be 480 tons per 10^6 bbls of feedstock. The control schedule used for this category is as follows:

YEAR	1973	1974	1975	1976	1977	1978
Chemical Storage Control Factor	.66	.46	.38	.34	.30	.30

Loading

Based on Engineering Science's 1975 inventory (1978) we worked out an uncontrolled loading emission factor of 32 tons per 10^6 bbls of feedstock for the chemical industry. The control schedule for chemical loading is as follows:

YEAR	1973	1974	1975	1976	1977	1978
Chemical Loading Control Factor	.89	.83	.80	.78	.78	.78

Natural Gas Processing

The 1975 emission level for natural gas refining reported by Engineering Science (1978) was used as a base number for this category. The number was divided among Harris, Chambers, Brazoria, Galveston, and the Ship Channel in proportion to the emissions from natural gas refineries listed in TACB's 1973 point source list (TACB 1978a). Volume figures for the industry came from the "Mineral Industry Surveys, Petroleum Statement Monthly" (BOM 1973-1978) listing for the Texas Gulf area. We assumed no controls for this category.

Other Stationary Hydrocarbon Sources

The volume of service station and vehicle loading (gasoline marketing) is dependent on gasoline sales or the vehicle miles traveled (VMT). Loading into service station tanks is assumed to be controlled according to the control schedule listed for refinery loading, with an uncontrolled factor of 7.05 pounds per 10^3 gallons loaded. Loading into the vehicle gas tanks is taken to be uncontrolled at 9.7 pounds per 10^3 gallons loaded (Engineering Science 1978). Assuming that vehicles travel an average of 11.6 miles per gallon of gas used (MVAA 1978), the emission factors become .111 tons per 10^3 VMT for uncontrolled service station loading, and .153 tons per 10^3 VMT for vehicle loading. Traffic volume for the area, as reported by the Houston-Galveston Transportation Study (H-GRTS 1974-1978) is as follows:

YEAR	1973	1974	1975	1976	1977	1978
10^3 VMT Per Day	36700	37200	40200	43400	46900	49900

Emissions from road surfacing were assumed to be proportional to VMT, and to have increased according to the same schedule. No controls have been applied to this process. The area-averaged emission factor we used (to match Engineering Science's 1975 inventory) was 0.04 tons per year per 10^3 VMT per day.

The drycleaning emission factor was decreased each year according to a schedule suggested by TACB (1975). The emission factor for 1975 was constructed to give a result that matches the Engineering Science (1978) report. The uncontrolled emissions were assumed to be proportional to the population as estimated by the Texas Employment Commission (1979).

YEAR	1973	1974	1975	1976	1977	1978
Dry Cleaning Controlled Emission Factor (tons per year/10^3 people)	1.13	1.08	1.08	1.03	.97	.97
Population (10^3 people)	2120	2210	2290	2390	2470	2432

The emission factor for paints has also decreased (TACB, 1975). These emissions too were taken to be proportional to population.

YEAR	1973	1974	1975	1976	1977	1978
Paint Controlled Emission Factor (tons per year/10^3 people)	1.2	.8	.5	.5	.5	.5

The hydrocarbon emissions from miscellaneous industrial sources and industrial paints (or surface coatings) reported here for 1975 match those of the Engineering Science (1978) inventory. Their "Other Point Sources" and "Minor Sources" are multiplied by .87 because the population of our study area is approximately .87 of theirs.

The degreasing and solvent evaporation figures are taken from the TACB 1977 inventory (TACB 1979). These sources, as well as those listed in the preceeding paragraph were considered to grow at 3% per year, a number suggested in the Engineering Science (1978) publication.

The emissions from residential, commercial, and industrial burning of fuels were taken directly from TACB's yearly area source inventories (TACB, 1978b).

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APPENDIX B

RESPONSE TO ISSUES RAISED BY INDUSTRIAL REPRESENTATIVES AND TACB PERSONNEL

When preliminary results of this study were presented at the APCA Specialty Conference on Ozone/Oxidants in Houston in October 1979, several new issues regarding historical emission trends were raised by industrial representatives and TACB personnel. The three major issues were as follows: (1) that a conservation program on natural gas and other fuels made chemical and petroleum industry NO_x emissions increase less rapidly than throughput (Walker 1979a); (2) that a voluntary tightening-up of hydrocarbon leaks reduced fugitive emissions in the chemical industry (Beck 1979); and (3) that our control schedules for the chemical and petroleum industries might be inaccurate (Stewart 1979). As further discussions were held with industrial personnel, even more new issues were raised.

During the last phase of this project, we did considerable further work investigating the new issues, revising our emission trend estimates, and repeating the isopleth validation studies. This appendix discusses the emission trend issues and describes the changes we made in our emission trend methodology.

In revising our emission trend estimates, we attempted to unearth as much information as possible. We revisited Austin and Houston and held discussions with the TACB, the City of Houston, and industrial representatives. We also made numerous telephone and written communications with the TACB, industrial representatives, and consulting firms. Despite this effort, we found that there was a lack of hard data concerning many of the issues. Thus, as discussed in Chapter 3, our latest work served to emphasize the uncertainties regarding emission trends in Houston.

CONSERVATION PROGRAMS

Walker (1979a) has suggested that NO_x emissions from stationary sources have been reduced due to voluntary fuel conservation efforts. There was, in fact, an agreement within the industrial community to reduce fuel consumption by 15% (per pound of product) over the years 1972 to 1980. Roeser (1980) at the TACB Houston Office reports that every industrial plant met or exceeded the conservation goal; some reduced fuel consumption per pound of product by as much as 25 or 30%.

It cannot be assumed, however, that NO_x emissions were reduced proportionately with fuel conservation. Recycling heat in order to conserve fuel does reduce NO_x. Burning waste gasses for fuel may reduce NO_x, if the waste gasses were previously flared. Some plants, on the other hand, conserved fuel by pre-heating; this greatly increases NO_x emissions.

There does not seem to be a way to quantify how much of each type of conservation activity (e.g. recycling, burning waste gasses, or pre-heating) has occurred. We do expect, nonetheless, that NO_x emissions per pound of product have decreased significantly from 1972 to 1980. For the purpose of this report we have chosen a "ball park" conservation factor of a 20% reduction in NO_x per pound of product. This factor has been applied linearly over the years 1972 to 1980 (i.e. 2.5% per year).

TIGHTENING-UP OF FUGITIVE EMISSIONS

The second major question -- "Were fugitive hydrocarbon emissions in the chemical industry reduced due to a voluntary tightening-up of leaks?" led to an interesting and controversial discussion. The major thrust of the "tightening-up" argument seems to center around the fact that old leaky plants have been replaced by newer tighter plants (Beck 1980). According to Mr. Beck, an important example is the ethylene industry. Almost one-third of petrochemical production in the Houston area is ethylene production (Engineering Science 1978). Because seven large new plants have been installed, ethylene capacity in the Houston area doubled from 1973 to 1978 (Beck 1980). Mr. Beck contends that, even though more ethylene is being produced, there should be a net decrease in fugitive hydrocarbons from the ethylene industry because the new ethylene plants are much tighter and because some old ethylene plants have been shut down.

Contrasting this opinion is the view of Burton (1980) of Pace Engineers. According to Mr. Burton, the old ethylene plants used ethane and propane for feedstock, while the new plants use naptha and gas oil. Because of the difference in feedstocks, and because the newer plants are much more complicated (requiring more valves, flanges, etc.), Mr. Burton believes that the newer ethylene plants have a higher hydrocarbon emissions rate per pound of product -- maybe higher by as much as a factor of five.

Although ethylene production is a large part of the organic chemical industry in Houston, it is responsible for only 4 to 5% of that industry's hydrocarbon emissions (Engineering Science 1978). It is, however, representative of the confusion surrounding the emissions in the chemical industry.

In summary, we were unable to obtain any definitive documentation of fugitive hydrocarbon emission reductions due to the tightening-up of chemical plants. Fortunately, this issue is not highly critical to our overall emission trends because fugitive emissions from the chemical industry represent only 5-9% of regionwide NMHC emissions (depending on the year). This issue is, however, critical to emission trends in the chemical industry per se because estimated fugitive emissions represent 14% of chemical industry NMHC in 1974 and 34% of chemical industry NMHC in 1978.

CONTROL SCHEDULES

We were unable to obtain any information which would suggest different control schedules than those contained in our preliminary report. Although the TACB (Stewart 1979) questioned the control schedules that we derived from their information, they were unable to supply any new data. The industrial representatives did not question our control schedules for NMHC.

OTHER SUGGESTIONS

Beck (1980) suggested that we might estimate trends in hydrocarbon emissions by comparing directly the 1973 TACB inventory, the 1975 TACB inventory, and the 1977 HAOS inventory. We believe that this method would be inappropriate. The methods used to derive the 1973 TACB inventory were quite different from those used to derive later inventories, so the inventories cannot be compared directly to estimate trends. Also, TACB personnel (Anderson 1979; Roeser 1980) have said that the 1973 inventory is likely to be in error because inventory techniques were not well developed in 1973.

In response to our objection to using the 1973 TACB inventory for estimating emission trends, Beck (1980) offered a version of the 1973 TACB inventory that he adjusted for discrepancies with the 1975 TACB inventory. We seriously question whether simple adjustments can be applied to make the 1973 inventory consistent with later inventories for the purpose of determining trends. Also, we note that Mr. Beck's adjusted 1973 inventory appears to be inconsistent with other information that he has provided. In particular, the chemical industry emissions in his adjusted 1973 inventory are much greater than would be obtained using the simple uncontrolled emission factor of 0.5% product loss that he suggested for the chemical industry. We hold firm in the opinion that emission trends cannot be estimated by comparing yearly inventories based on disparate assumptions and methods; rather, emission trends must be calculated by using a single baseline inventory and by applying growth and control schedules to the various source categories in that baseline inventory.

We did adopt a suggestion by Beck (1980) that we use new data sources to estimate growth in chemical industry throughput. Previously, we used Bureau of Mines Yearbook data regarding refinery output of petrochemical feedstock to estimate growth in chemical industry throughput. Beck (1980) suggested that we use the Chemical Week Chemical Output Index and the Oil and Gas Journal plant-by-plant list of ethylene capacity to estimate the chemical industry growth trend. Ethylene capacity data (Oil and Gas Journal) were available only after 1975, so we used those data for the years 1976-1978. The Chemical Output Index (Chemical Week) represents nationwide trends only; we used these data for the years 1973-1976. The reader is referred to Appendix A for a more detailed description of the method used to calculate petrochemical growth. It should be noted that this new method produces somewhat less growth than our old method (a 78% increase form 1974 to 1978 as opposed to our previous estimate of a 97% increase from 1974 to 1978). It is not clear that the new method yields a more accurate estimate of petrochemical trends than cur old method. The new method is, however, the method suggested by personnel in the chemical industry.

Since the time we completed our original report, the HAOS point source inventory for 1977 has been published. Because all parties seem to agree that the HAOS inventory is the most accurate one available, we used it as a base year (1977) inventory for the chemical and petroleum industries. We found that the HAOS NMHC inventory agreed extremely well with our previous NMHC inventory, but that the HAOS NO_x inventory indicated much lower emissions than our previous NO_x inventory. Thus, the main change produced by using the HAOS inventory concerned NO_x emissions.

It should be noted that there are a few curiosities with respect to the HAOS inventory. The HAOS inventory is presented as a gridded map with emissions listed for each 4 X 4 kilometer grid square. The TACB Houston office (Roeser 1980) provided us with a 1977 point source list. Presumably, the HAOS inventory was derived using the TACB list. However, when we tried to match the inventories, we found several discrepancies. Inventories for individual counties differed by as much as 18%. Also, when each entry of the TACB list is placed on a map and the emissions are compared area by area, we find differences as much as 100% for some areas. For example, the TACB list indicates only one source, Celanese Chemical Company, with 1598 tons/year NMHC in the Bayport area of Harris County; the HAOS inventory assigns that area only 787 tons/year of NMHC.

Another curiosity is the claim that the TACB point source list of the thirty largest companies represents more than 90% of the total point source emissions. According to the 1973 TACB inventory (admittedly in error according to the TACB but possibly accurate according to industry personnel), the same thirty sources were responsible for only 56% of point source emissions.

The HAOS inventory is also questionable because "arbitrary corrections" have been made to that inventory. For example, 20,000 tons/year of NMHC and 9,000 tons/year of NO_x were arbitrarily subtracted from the initial emission estimates for a single large point source (Walker 1979b). The arbitrary correction for this single point source amounts to around 5% of regionwide emissions.

We have pointed out the above curiosities with regard to the HAOS inventory to emphasize the fact that even the HAOS inventory contains significant uncertainty. All in all, we are not sure that we have improved the accuracy of our emission trends by using the HAOS point source inventory as a baseline rather than the inventories that we originally constructed ourselves.

CHANGES IN OUR EMISSION TREND ESTIMATES

The revisions to our emission trend methodology had a very significant effect on our estimates of historical NO_x emission trends. Previously, we had estimated that NO_x emissions increased by 50% regionwide from 1974 to 1978; our revised estimate is only an 18% increase from 1974 to 1978. Most of this change is due to the use of the HAOS inventory which indicated much lower baseline emissions for the rapidly growing source categories (the chemical and petroleum industries) and to the addition of factors which account for fuel conservation in the chemical and petroleum industries. A minor part of this change is due to the new growth factors used for the chemical industry. As discussed in Chapter 3, the ambient trend data for NO_x show larger increases from 1974 to 1978 than do our latest emission trend estimates. Considering the uncertainties in our analysis, it is quite possible that we have underestimated historical increases in NO_x emissions.

Our revised estimates of emission trends for NMHC are not very different from our previous estimates. Previously we calculated that regionwide NMHC emissions decreased 4% from 1974 to 1978; our latest results indicate a 7% decrease from 1974 to 1978; One major reason why our emission estimates for NMHC have not changed much with the new methodology is that the HAOS inventory for NMHC agrees well with our previous baseline inventory. The basic reason why we find a slightly greater regionwide NMHC decrease from 1974 to 1978 than we found previously is that we have used new estimates of growth rates in the chemical industry.

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APPENDIX C

ACTUAL OZONE TRENDS AT MAE DRIVE COMPARED TO PREDICTED TRENDS FOR VARIOUS NMHC/NO$_x$ RATIOS

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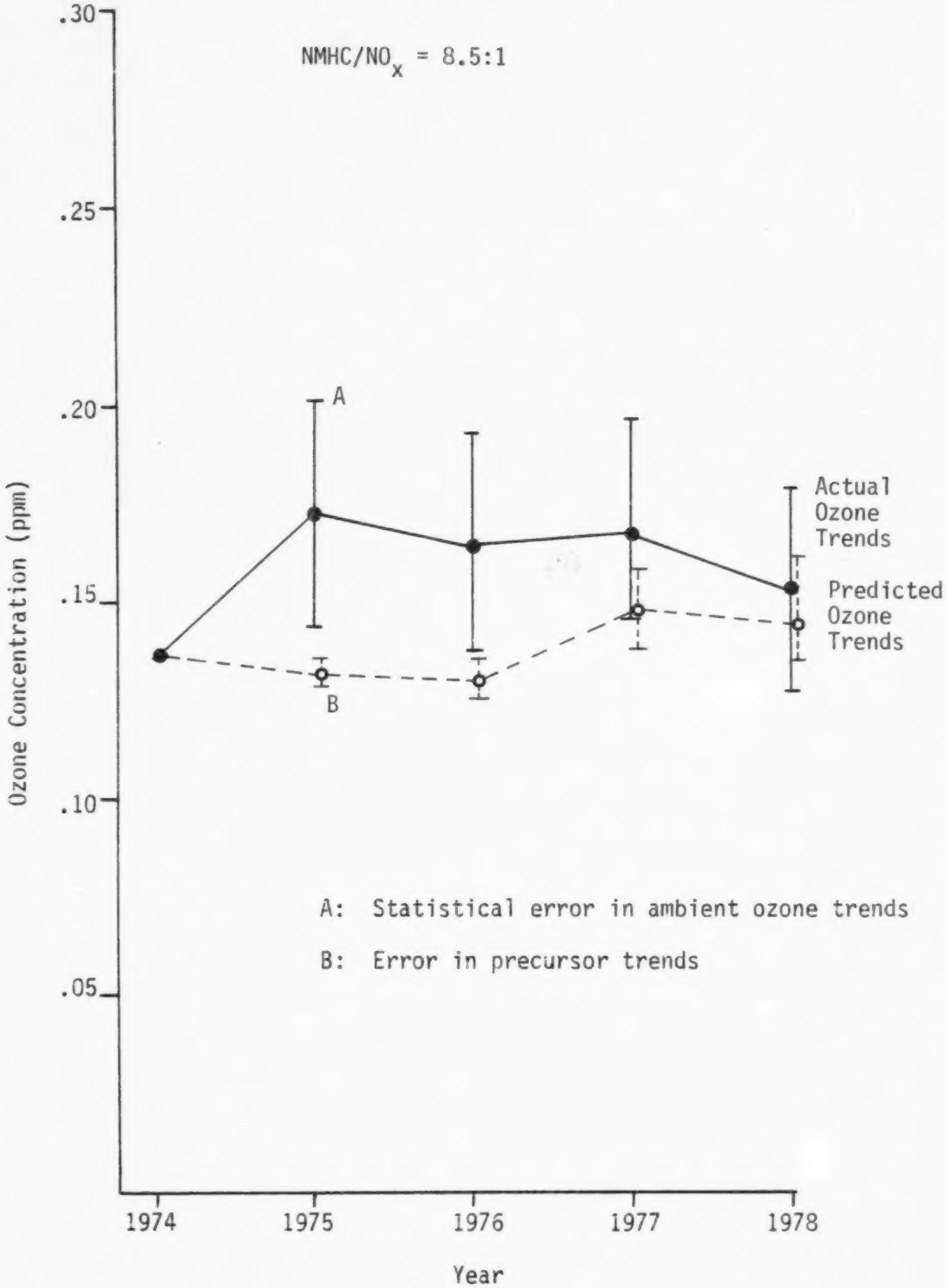

Figure C-1. Ozone trends in the 95th percentile of daily maxima at Mae Drive, predicted for 8.5:1 ratio versus actual.

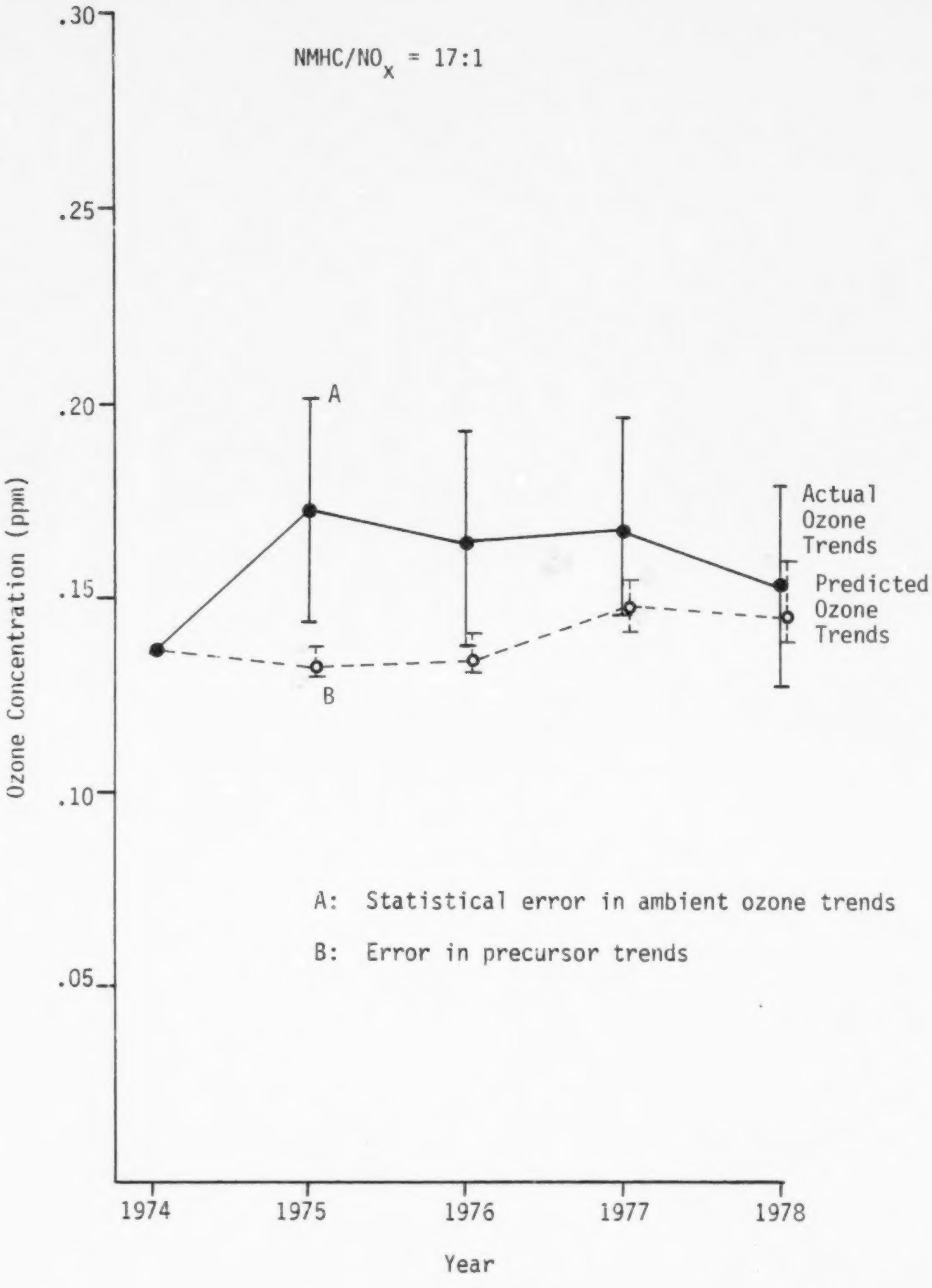

Figure C-2. Ozone trends in the 95th percentile of daily maxima at Mae Drive, predicted for 17:1 ratio versus actual.

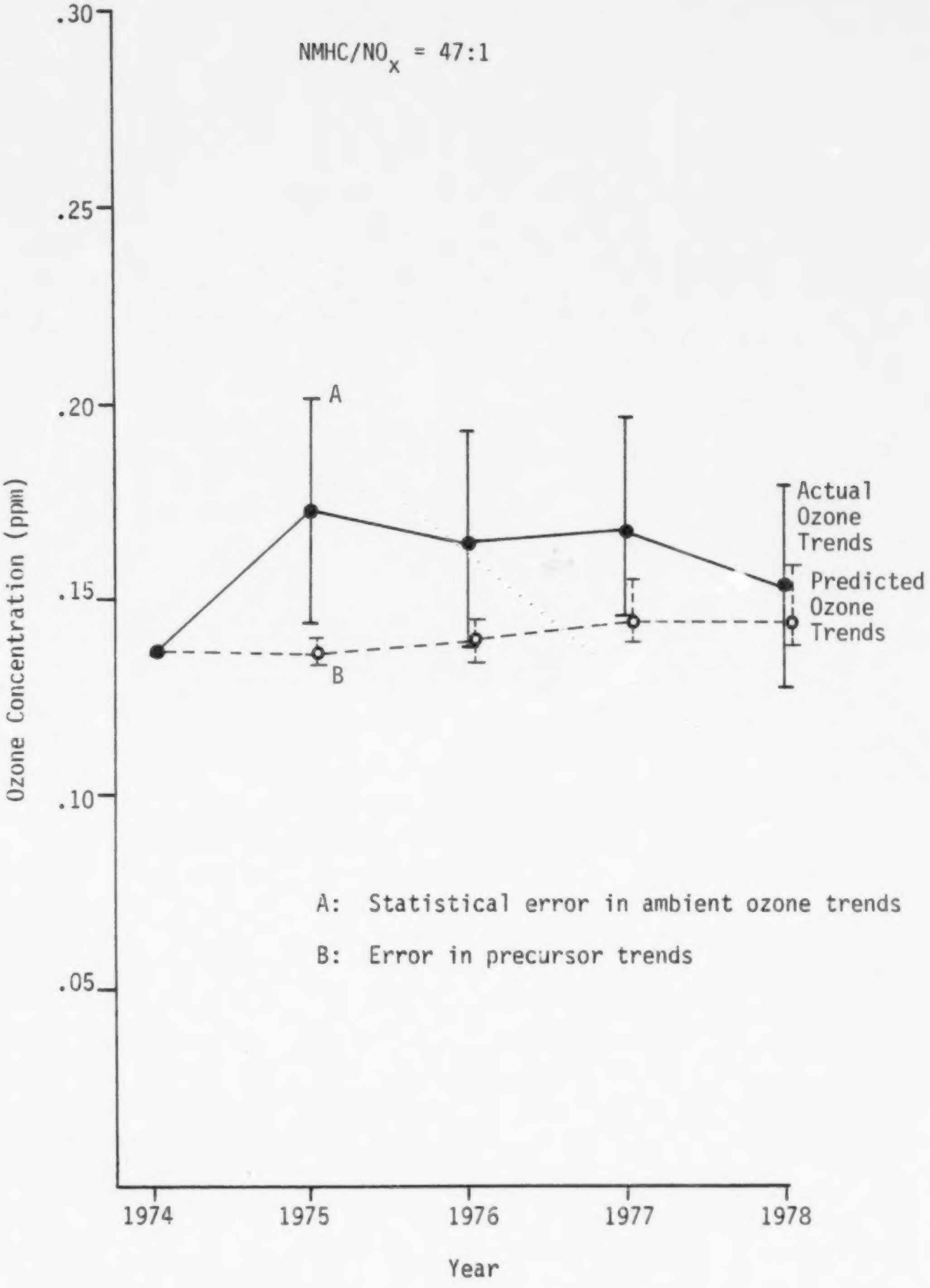

Figure C-3. Ozone trends in the 95th percentile of daily maxima at Mae Drive, predicted for 47:1 ratio versus actual.

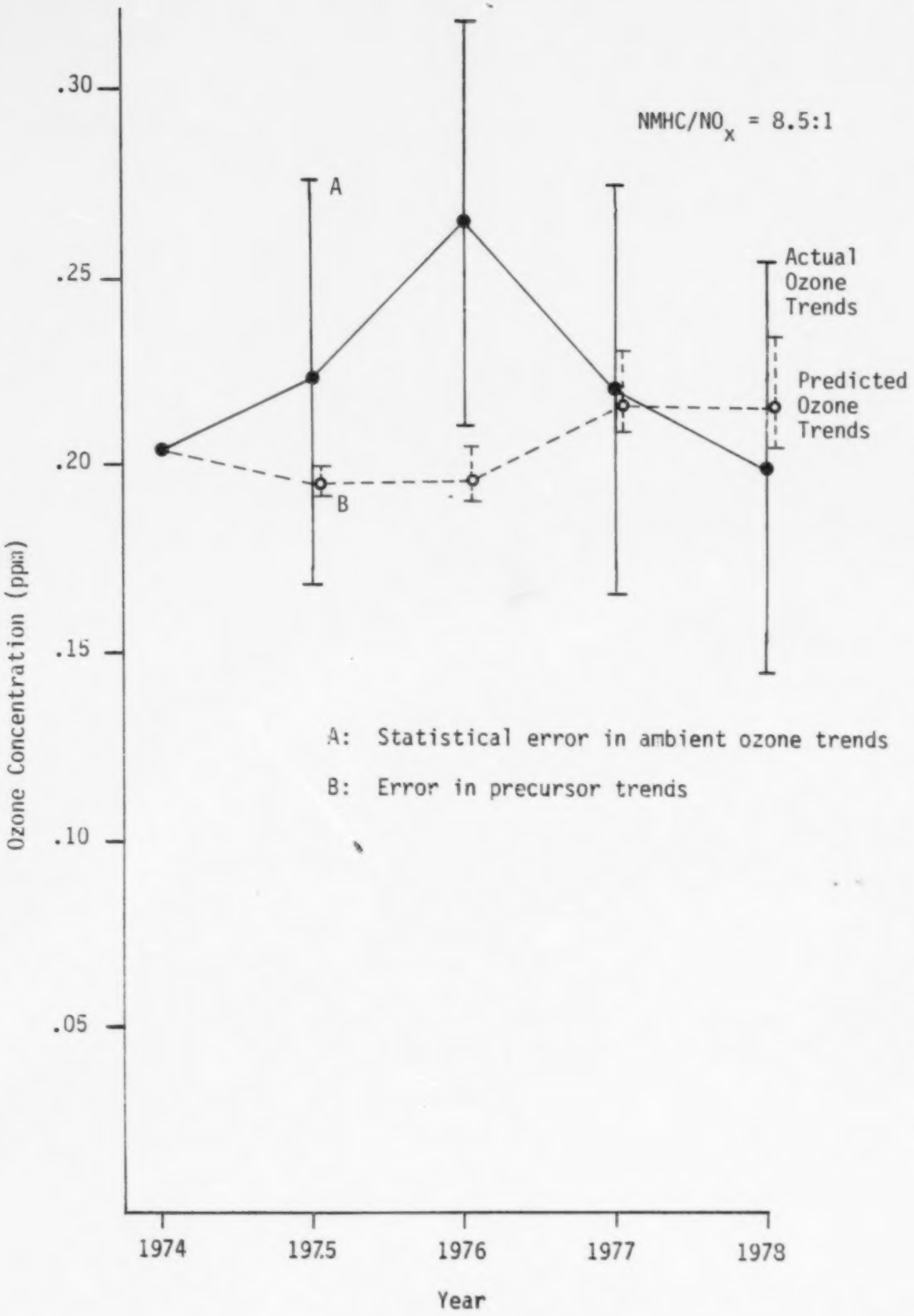

Figure C-4. Ozone trends in the yearly second maximum at Mae Drive, predicted for 8.5:1 ratio versus actual.

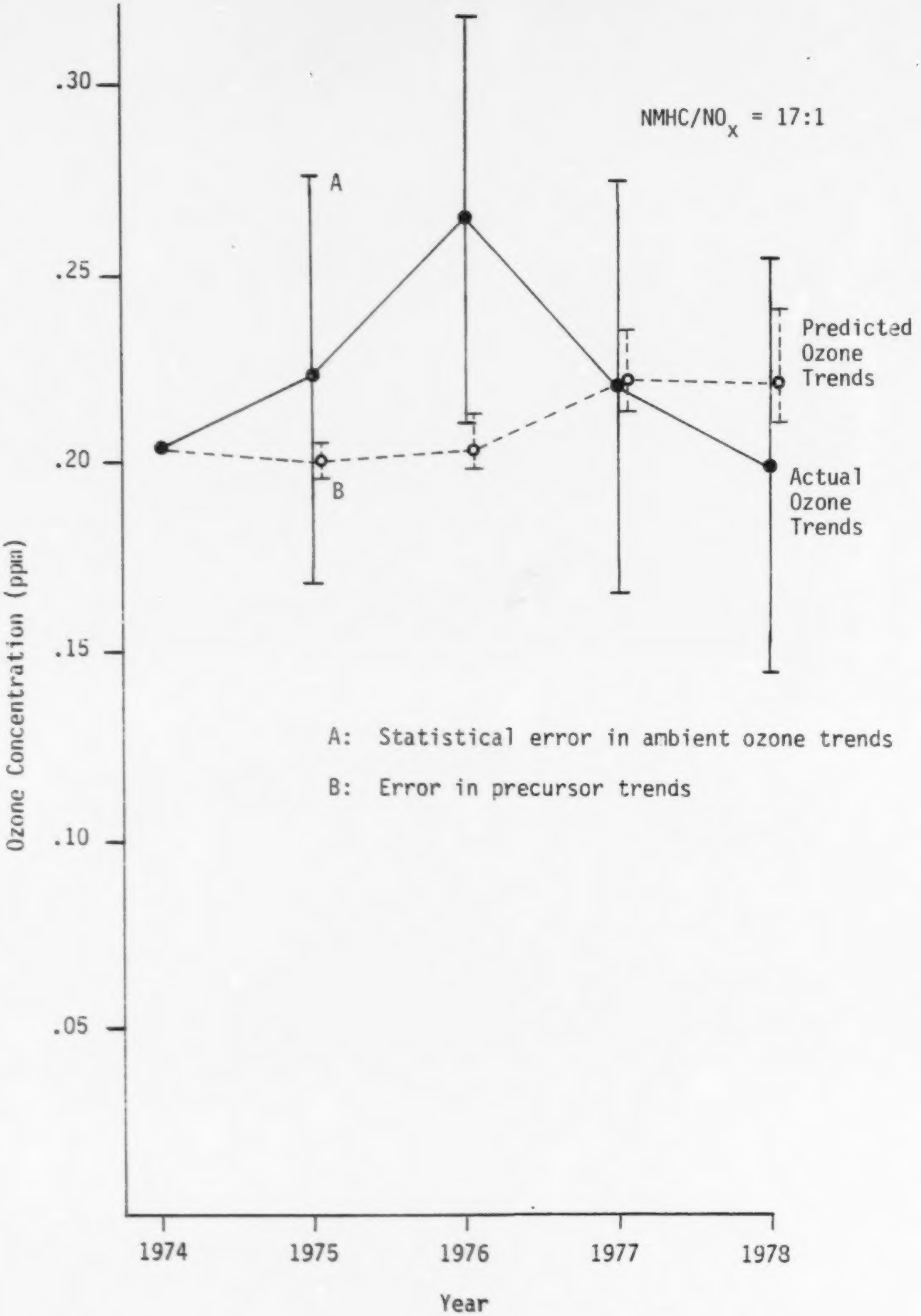

Figure C-5. Ozone trends in the yearly second maximum at Mae Drive, predicted for 17:1 ratio versus actual.

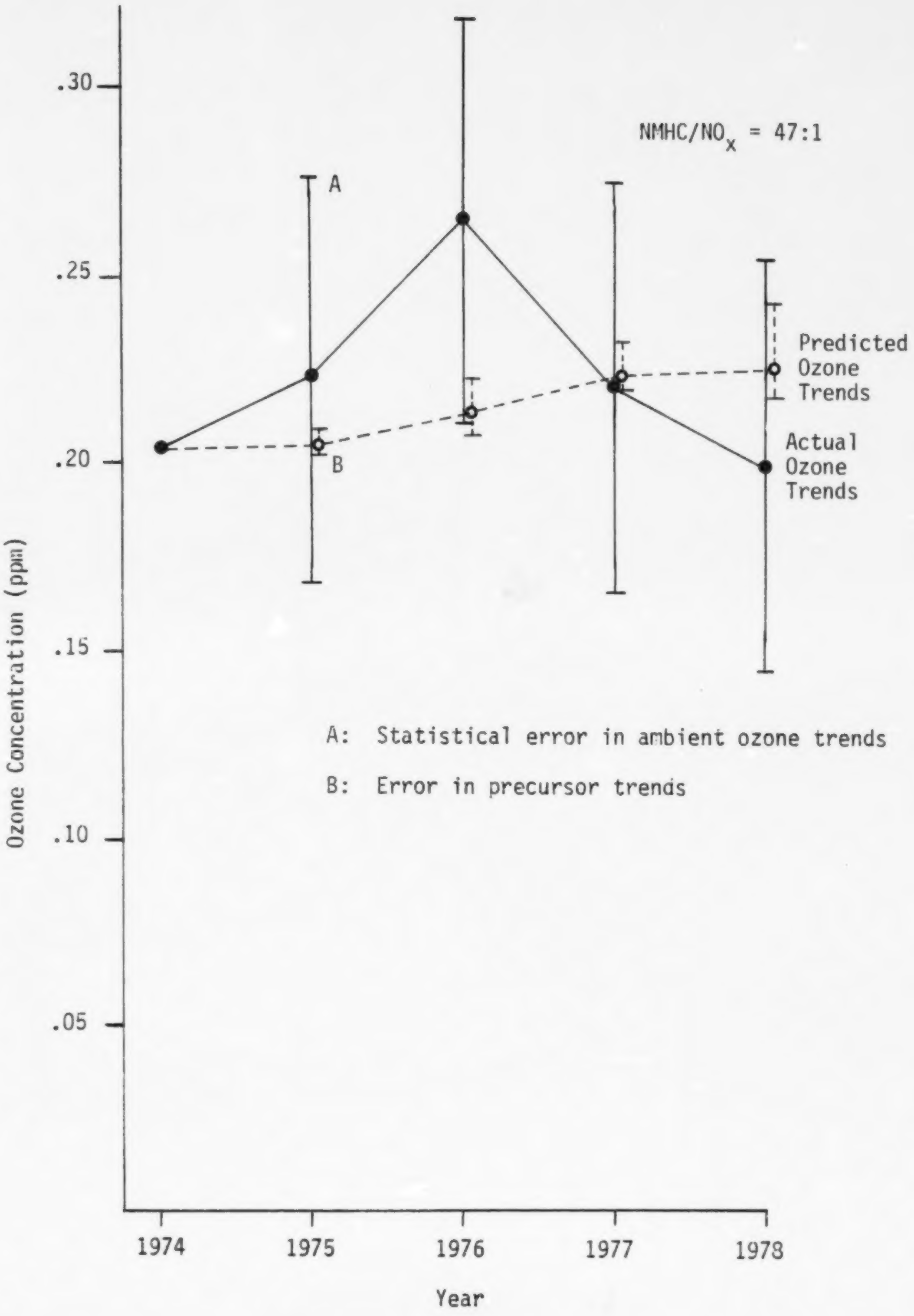

Figure C-6. Ozone trends in the yearly second maximum at Mae Drive, predicted for 47:1 ratio versus actual.

APPENDIX D

ACTUAL OZONE TRENDS AT ALDINE COMPARED TO PREDICTED TRENDS FOR VARIOUS NMHC/NO_x RATIOS

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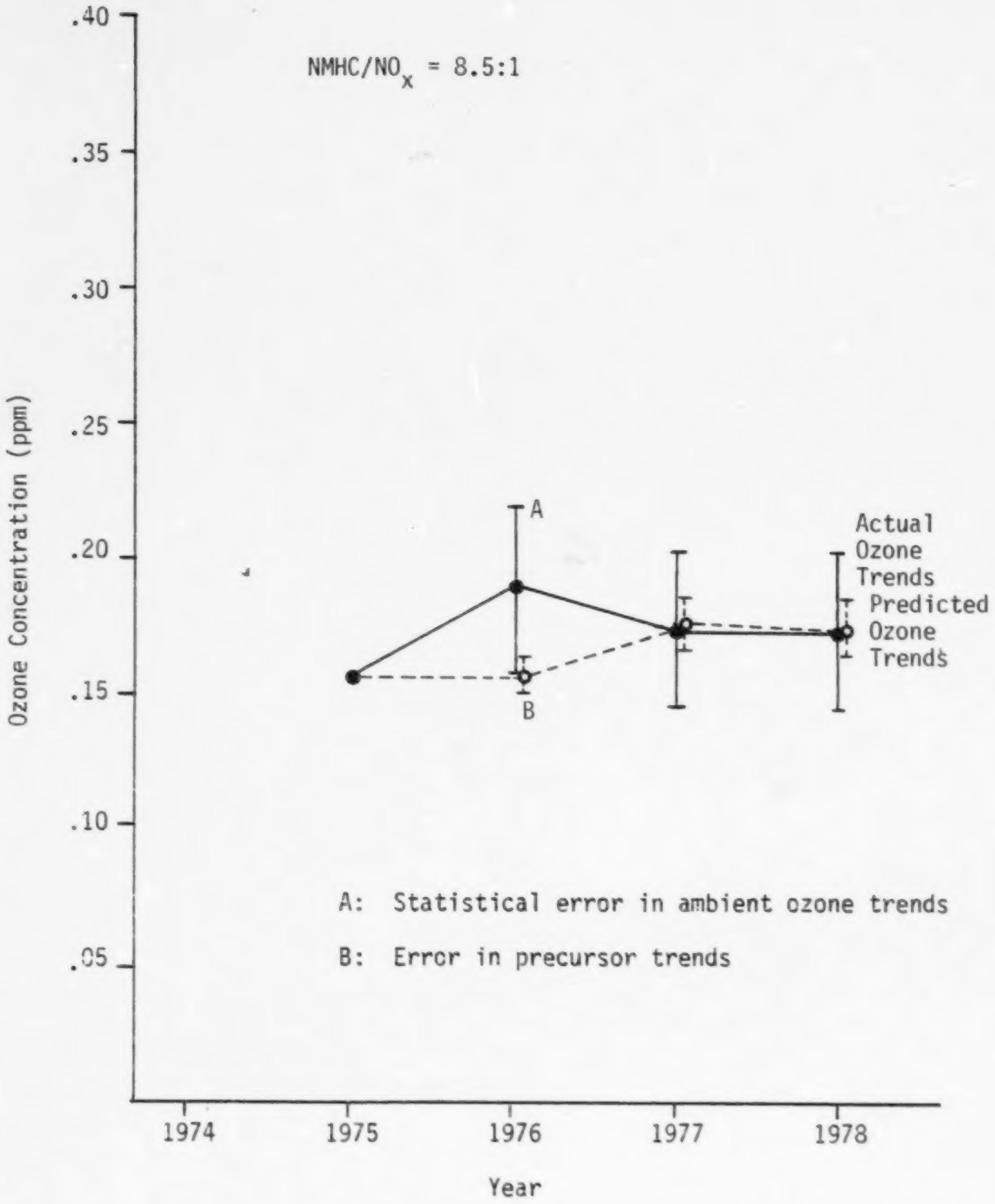

Figure D-1. Ozone trends in the 95th percentile of daily maxima at Aldine, predicted for 8.5:1 versus actual.

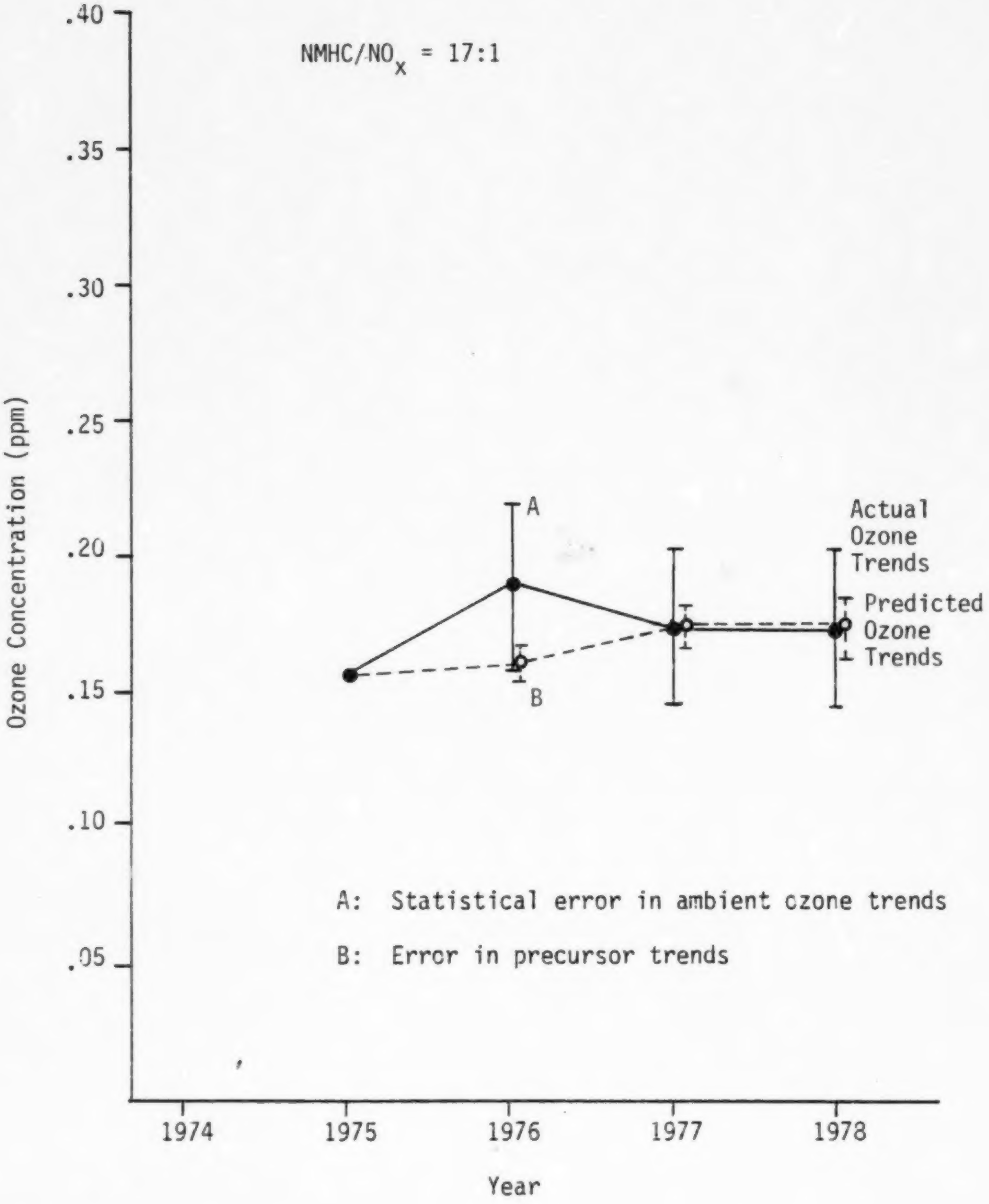

Figure D-2. Ozone trends in the 95th percentile of daily maxima at Aldine, predicted for 17:1 ratio versus actual.

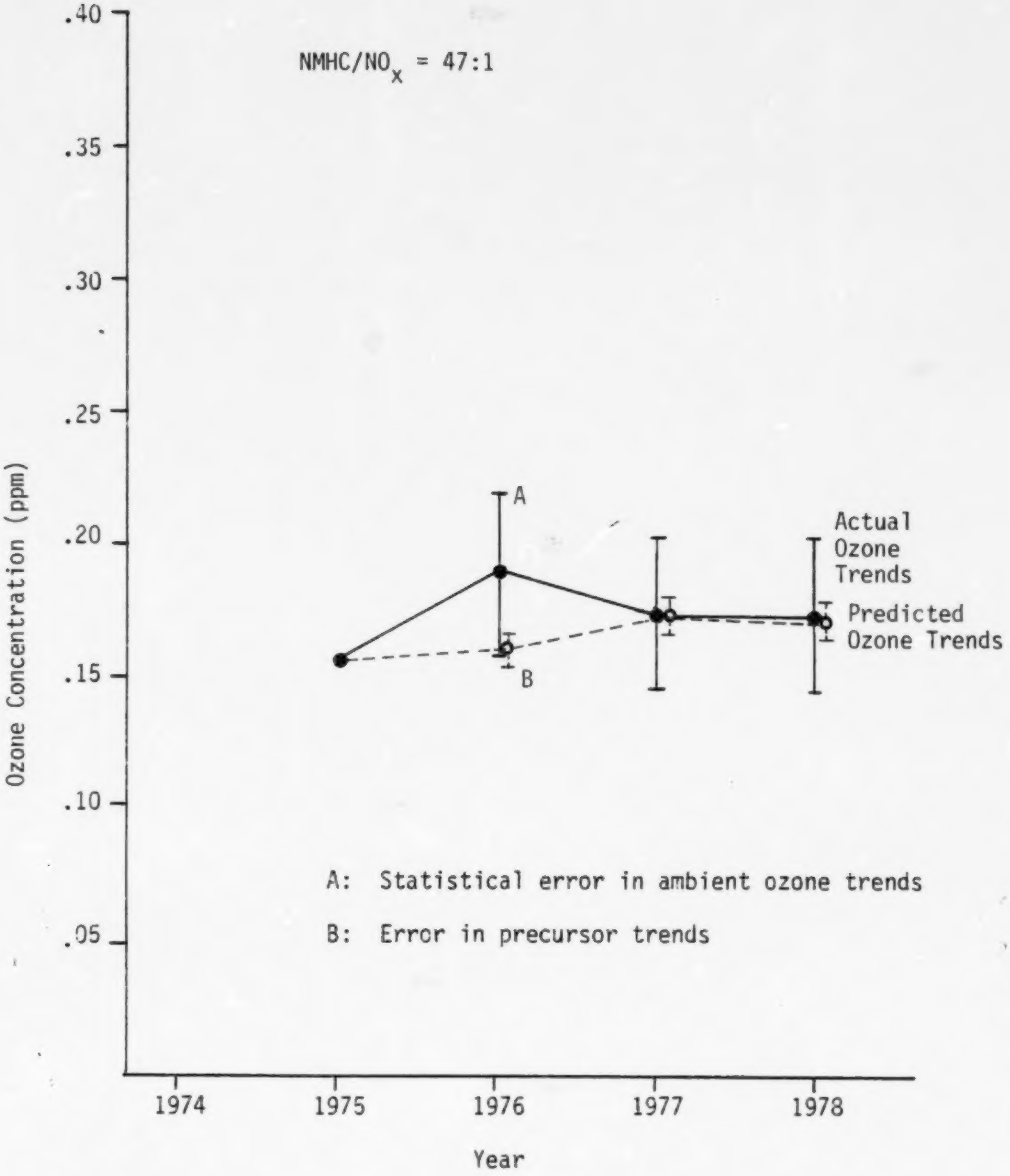

Figure D-3. Ozone trends in the 95th percentile of daily maxima at Aldine, predicted for 47:1 ratio versus actual

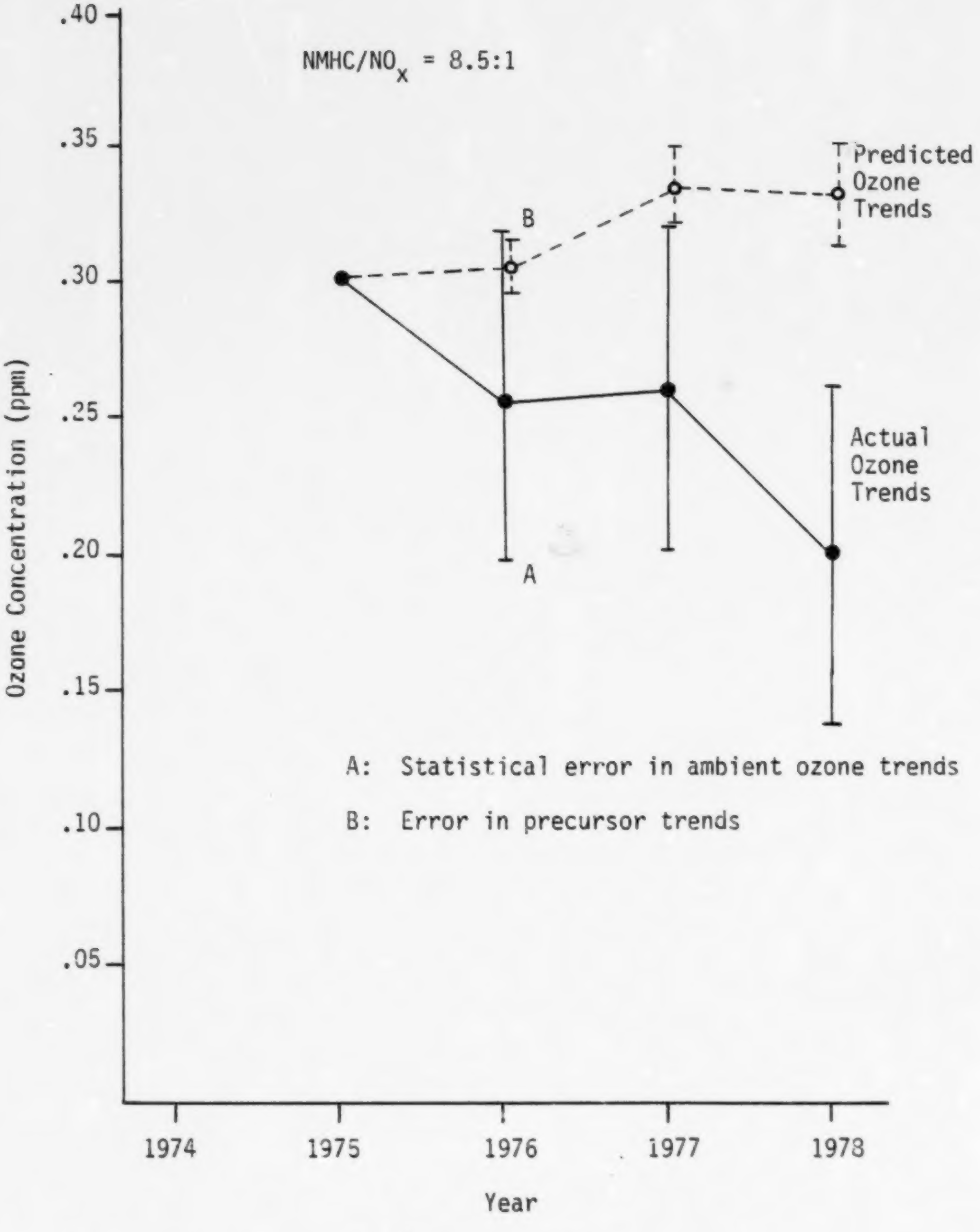

Figure D-4. Ozone trends in the yearly second maximum at Aldine, predicted for 8.5:1 ratio versus actual.

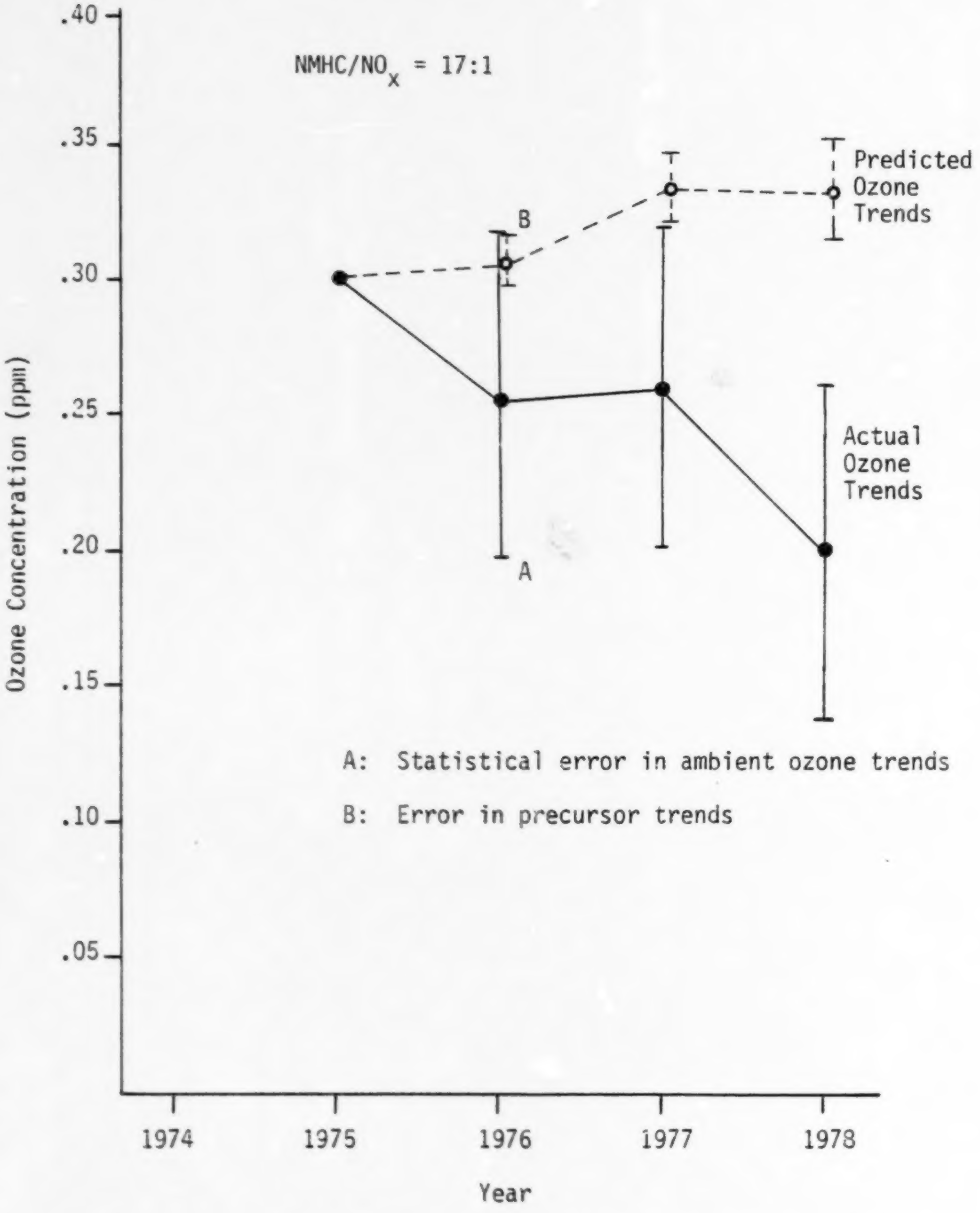

Figure D-5. Ozone trends in the yearly second maximum at Aldine, predicted for 17:1 ratio versus actual.

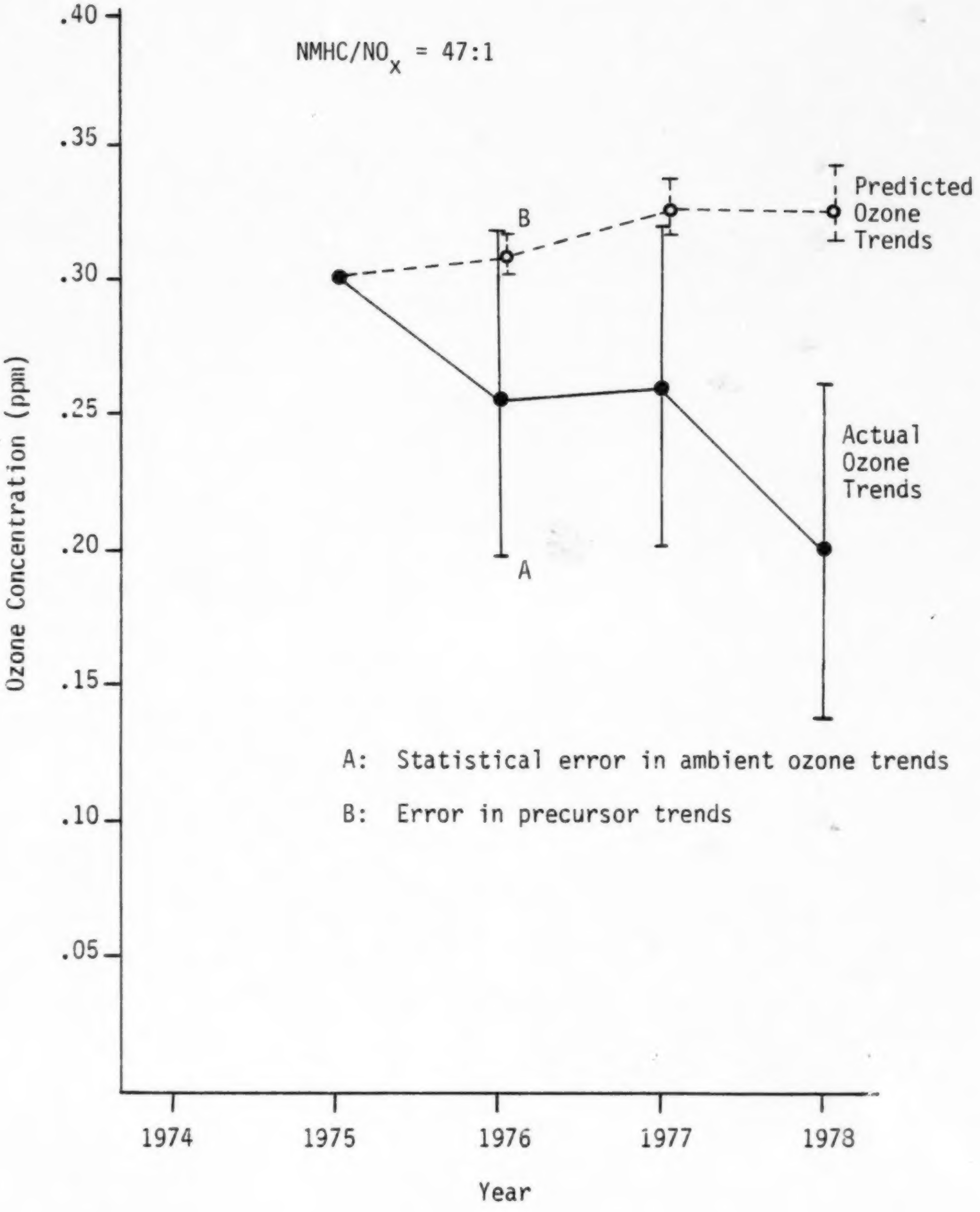

Figure D-6. Ozone trends in the yearly second maximum at Aldine, predicted for 47:1 ratio versus actual.